September, 2007
07/31/WQPC-WWF
EPA/600/R-07/121

Environmental Technology Verification Report

Stormwater Source Area Treatment Device

Hydro International Downstream Defender®

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

`THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**STORMWATER TREATMENT TECHNOLOGY**	
APPLICATION:	**SUSPENDED SOLIDS TREATMENT**	
TECHNOLOGY NAME:	**DOWNSTREAM DEFENDER®, 6-ft DIAMETER**	
TEST LOCATION:	**MADISON, WISCONSIN**	
COMPANY:	**HYDRO INTERNATIONAL**	
ADDRESS:	**94 Hutchins Drive** **Portland, Maine 04102**	PHONE: **(207) 756-6200** FAX: **(207) 756-6212**
WEB SITE:	**http://www.hydrointernational.biz/us/**	
EMAIL:	**stormwaterinquiries@hil-tech.com**	

NSF International (NSF), in cooperation with the U.S. Environmental Protection Agency (EPA), operates the Water Quality Protection Center (WQPC), one of six centers under the Environmental Technology Verification (ETV) Program. The WQPC recently evaluated the performance of a 6-ft Downstream Defender®, manufactured by Hydro International. The Downstream Defender® was installed at the Madison Water Utility in Madison, Wisconsin. Earth Tech, Inc. and the United States Geologic Survey (USGS) performed the testing.

EPA created ETV to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The ETV program's goal is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

TECHNOLOGY DESCRIPTION

The following description of the Downstream Defender® was provided by the vendor and does not represent verified information.

The Downstream Defender® is a hydrodynamic vortex separator designed to remove settleable solids (and their associated pollutants), oil, and floatables from stormwater runoff. It consists of a cylindrical concrete vessel, with plastic internal components and a 304 stainless steel support frame and connecting hardware. The concrete vessel is a standard pre-cast cylindrical manhole with a tangential inlet pipe installed below ground. Two ports at ground level provide access for inspection and clean out of stored floatables and sediment. The internal components consist of two concentric hollow cylinders (the dip plate and center shaft), an inverted cone (the center cone), a benching skirt, and a floatables lid.

The Downstream Defender® is self-activating, and operates on simple fluid dynamics. The geometry of the internal components and placement of the inlet and outlet pipes are designed to direct the flow in a pre-determined path through the vessel. Stormwater is introduced tangentially into the side of the vessel, initially spiraling around the perimeter in the outer annular space between the dip plate cylinder and manhole wall. Oil and floatables rise to the water surface and are trapped by the dip plate in the outer annular space. As the flow continues to rotate about the vertical axis, it travels down towards the bottom of the dip plate. Low energy vortex motion directs sediment toward the center and base of the vessel. Flow passes under the dip plate and up through the inner annular space, between the dip plate and center shaft, as a narrower spiraling column rotating at a slower velocity than the outer downward flow. The outlet of the Downstream Defender® is a single central discharge from the top water level in the inner annulus.

Performance of the Downstream Defender®, in terms of sediment removals, depends on the incoming flow rate, particle size distribution, specific gravity, and runoff temperature. According to Hydro International, for runoff at 15 C°, the Downstream Defender® will remove over 80% of settleable solids with a specific gravity of 2.65 and a particle size distribution similar to Maine DOT road sand at flow rates up to 3 cfs. Flows exceeding the design capacity (3 cfs for the tested system) would be bypassed by a weir system installed upstream of the Downstream Defender®.

VERIFICATION TESTING DESCRIPTION

Methods and Procedures

The test methods and procedures used during the study are described in the *Test Plan for the Verification of. Downstream Defender® "Madison Water Utility Administration Building Site" Madison, Wisconsin September 30, 2005*. The Downstream Defender® was installed to treat runoff collected from a paved parking area at the Madison Water Utility in Madison, Wisconsin. Madison receives an average annual precipitation of nearly 33 in., with an average snowfall of 44 in.

Verification testing consisted of collecting data during a minimum of 15 qualified events that met the following criteria:

- The total rainfall depth for the event, measured at the site, was 0.2 in. (5 mm) or greater;
- Flow through the treatment device was successfully measured and recorded over the duration of the runoff period;
- A flow-proportional composite sample was successfully collected for both the inlet and the outlet over the duration of the runoff event;
- Each composite sample was comprised of a minimum of five aliquots, including at least two aliquots on the rising limb of the runoff hydrograph, at least one aliquot near the peak, and at least two aliquots on the falling limb of the runoff hydrograph; and
- There was a minimum of six hours between qualified sampling events.

Automated sample monitoring and collection devices were installed and programmed to collect composite samples from the inlet, system outlet, bypass, and combined discharge (system plus bypass) during qualified flow events. In addition to the flow and analytical data, operation and maintenance (O&M) data were recorded. Samples were analyzed for total suspended solids (TSS), suspended sediment concentration (SSC), total dissolved solids (TDS), volatile suspended solids (VSS), and particle size distribution. The TSS analytical method was modified for samples with a heavy settleable sediment load using a procedure developed by USGS. The adjusted TSS method was designed to provide an improved methodology for measuring large, dense sediment particles in samples. Refer to the verification report for additional details about the modified TSS method.

VERIFICATION OF PERFORMANCE

Verification testing of the Downstream Defender® lasted approximately 17 months, and coincided with testing conducted by USGS and the Wisconsin Department of Natural Resources. A total of 20 storm events were sampled.

Test Results

The precipitation data for the rain events are summarized in Table 1. Peak flow rates exceeded the rated treatment capacity of the Downstream Defender® during events 5, 6, 19 and 20. These events were large and intense, and it appeared that runoff from an adjacent drainage area may have contributed additional flow and organic solids loading to the unit during these events.

The monitoring results were evaluated using event mean concentration (EMC) and sum of loads (SOL) comparisons. The EMC evaluates treatment efficiency on a percentage basis by dividing the outlet concentration by the inlet concentration and multiplying the quotient by 100. The EMC was calculated for each analytical parameter and each storm event. The SOL comparison evaluates the treatment efficiency on a percentage basis by comparing the sum of the inlet and outlet loads (the parameter concentration multiplied by the runoff volume) for all storm events. The calculation is made by subtracting from one the quotient of the total outlet load divided by the total inlet load, and multiplying by 100. SOL results can be summarized on an overall basis since the loading calculation takes into account both the concentration and volume of runoff from each event. The analytical data ranges, EMC range, and SOL reduction values are shown in Table 2.

The ratio of organic sediment to total sediment was measured by evaluating the ratio of VSS to TSS or SSC. This ratio showed a median organic sediment loading of 21% over all events, with a range of 4.7% to 67% during individual events. Organic materials, which include grass or leaf debris, are less dense than inorganic sediments, such as soil. The vendor claims that the Downstream Defender® is not as effective at removing lower-density organic solids from runoff.

A particle size gradation was conducted to quantify percentage (by weight) of particles ranging from >500 µm to <2 um, and the SOL was recalculated based on particle sizes. The particle size distribution of the sediments encountered at this site was significantly finer than the Maine DOT road sand and F-110 Silica Sand which formed the basis of product claims. For the range of solids encountered at this site, the Downstream Defender® removed 90% of particles larger than 250 µm on a cumulative basis. As shown in Table 3, the Downstream Defender® removed 78% of the particles greater than 125 µm and 67% of the particles greater than 63 µm on a cumulative basis.

System Operation

The Downstream Defender® was installed prior to verification, so verification of installation procedures on the system was not documented. It was thoroughly cleaned prior to the start of verification testing.

The Downstream Defender® was inspected periodically during verification, and no significant issues were noted. By the end of the verification test, the sediment chamber contained sediment at an approximate average depth of 0.35 ft. A particle size distribution analysis conducted on the retained solids showed that approximately 93% of the retained solids were 125 µm or larger. No specific gravity analysis was conducted for the captured solids; however, visual inspections suggested significant organic content. The dry weight of the retained solids was 416 pounds.

Table 1. Rainfall Data Summary

Event Number	Date	Start Time	Rainfall Amount (in.)	Rainfall Duration (hr:min)	Runoff Volume (ft^3)[2]	Peak Flow Rate (cfs)[2]	Water Temp. (°C)
1	3/8/06	18:03	0.71	4:36	1,880	1.0	3.5
2	3/12/06	18:34	0.43	9:25	1,370	0.42	4.6
3	4/2/06	20:41	1.01	10:01	5,910	0.38	15.5
4	4/12/06	5:07	0.37	2:56	1,980	0.63	--[3]
5[1]	4/16/06	4:15	1.13	12:44	6,230	5.8[1]	--[3]
6	4/29/06	17:18	1.65	25:38	8,480	0.66	--[3]
7	5/1/06	21:16	0.25	0:26	1,570	2.0	---[3]
8	5/9/06	12:01	0.37	6:50	2,090	0.35	15.4[4]
9	5/11/06	6:59	0.86	23:55	5,040	0.18	10.5[4]
10	5/17/06	15:36	0.23	2:02	1,310	0.85	14.8[4]
11	6/25/06	17:34	0.79	15:41	4,250	0.67	19.0[4]
12	7/9/06	19:45	0.36	0:08	1,430	2.6	24.8[4]
13	7/11/06	8:44	1.87	8:51	10,990	1.5	20.7[4]
14	7/19/06	21:43	0.96	9:44	4,680	2.5	22.8[4]
15	7/22/06	16:51	0.36	0:30	1,860	1.9	23.0[4]
16[1]	7/27/06	12:27	2.16	1:30	7,150	6.5[1]	24.0[4]
17	8/6/06	6:53	0.71	5:08	3,630	0.50	23.4[4]
18	8/17/06	16:27	0.29	1:45	1,300	1.3	22.4[4]
19[1]	8/23/06	23:06	1.60	8:17	13,450	4.4[1]	22.4[4]
20[1]	8/24/06	13:30	1.35	2:13	17,180	4.6[1]	22.8[4]

1. Peak flow capacity was exceeded and bypass flows were sampled.
2. Runoff volume and peak discharge rate measured at the inlet monitoring point. See the verification report for further details.
3. Temperature not recorded due to equipment malfunction.
4. Water temperature recorded at a nearby stormwater sampling site monitored by Wisconsin Department of Natural Resources.

Table 2. Analytical Data, EMC Range, and SOL Reduction Results

Parameter	Inlet range (mg/L)	Outlet range (mg/L)	EMC range (%)	SOL reduction w/o bypass (%)	SOL reduction all events inc. bypass (%)
TSS	23 – 700	19 – 584	-51 – 62	27	22
SSC	22 – 904	21 – 662	-47 – 70	42	33
TDS	<50 – 260	<50 – 238	-163 – 55	1	1
VSS	9 – 76	10 – 76	-82 – 19	-7	-6

Table 3. Sediment Sum of Load Results by Particle Size Category

Particle Size Category (µm)	DD Inlet (lb)	DD Outlet (lb)	Bypass (lb)	Individual Particle Size Load: DD Efficiency (%)	Individual Particle Size Load: System Efficiency (%)	Cumulative Particle Size Load: DD Efficiency (%)	Cumulative Particle Size Load: System Efficiency (%)
> 500	453	39	32	91	85	91	85
250-500	449	49	58	89	79	90	82
125-250	150	146	49	3	2	78	69
63-125	128	156	56	-2	-15	67	58
32-63	122	122	31	0	0	61	52
14-32	517	550	164	-6	-5	42	34

Quality Assurance/Quality Control

NSF personnel completed a technical systems audit during testing to ensure that the testing was in compliance with the test plan. NSF also completed a data quality audit of at least 10% of the test data to ensure that the reported data represented the data generated during testing. In addition to QA/QC audits performed by NSF, EPA personnel conducted an audit of NSF's QA Management Program.

Original signed by
Sally Gutierrez *October 15, 2007*
Sally Gutierrez Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original signed by
Robert Ferguson *October 3, 2007*
Robert Ferguson Date
Vice President
Water Systems
NSF International

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report is not an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents

Copies of the *ETV Verification Protocol, Stormwater Source Area Treatment Technologies Draft 4.1, March 2002,* the verification statement, and the verification report (NSF Report Number 07/31/WQPC-WWF) are available from:

ETV Water Quality Protection Center Program Manager (hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140

NSF website: http://www.nsf.org/etv (electronic copy)
EPA website: http://www.epa.gov/etv (electronic copy)
Appendices are not included in the verification report, but are available from NSF upon request.

Environmental Technology Verification Report

Stormwater Source Area Treatment Device

Hydro International.
Downstream Defender®

Prepared for:
NSF International
Ann Arbor, MI 48105

Prepared by:
Earth Tech Inc.
Madison, Wisconsin

With assistance from:
United States Geologic Survey (Wisconsin Division)
Wisconsin Department of Natural Resources

Under a cooperative agreement with the U.S. Environmental Protection Agency

Raymond Frederick, Project Officer
ETV Water Quality Protection Center
National Risk Management Research Laboratory
Water Supply and Water Resources Division
U.S. Environmental Protection Agency
Edison, New Jersey

September, 2007

Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under a Cooperative Agreement. The Water Quality Protection Center (WQPC), operating under the Environmental Technology Verification (ETV) Program, supported this verification effort. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA). The verification test for the Downstream Defender® was conducted at a testing site in Madison Wisconsin, owned and operated by the City of Madison Water Utility.

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Contents

Figures

Tables

Abbreviations and Acronyms

ASTM	American Society for Testing and Materials
BMP	Best Management Practice
cfs	Cubic feet per second
DD	Hydro International's Downstream Defender®
DOT	Department of Transportation (reference to Maine DOT)
EMC	Event mean concentration
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
ft	Foot or feet
ft^2	Square feet
ft^3	Cubic feet
g	Gram
gal	Gallon
gpm	Gallon per minute
hr	Hour
in.	Inch
kg	Kilogram
L	Liters
L/min	Liters per minute
lb	Pound
LOD	Limit of detection
LOQ	Limit of quantification
MH	Manhole
mm	Millimeter
NRMRL	National Risk Management Research Laboratory
μm	Micron
mg/L	Milligram per liter
min	Minute
MS/MSD	Matrix spike/matrix spike duplicate
NSF	NSF International, formerly known as National Sanitation Foundation
NIST	National Institute of Standards and Technology
O&M	Operations and maintenance
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RPD	Relative percent difference
SSC	Suspended sediment concentration
SOL	Sum of loads
SOP	Standard operating procedure
Std. Dev.	Standard deviation
TDS	Total dissolved solids
TO	Testing Organization
TSS	Total suspended solids
USGS	United States Geological Survey
VO	Verification Organization (NSF)

VSS	Volatile suspended solids
WDNR	Wisconsin Department of Natural Resources
WQPC	Water Quality Protection Center
WisDOT	Wisconsin Department of Transportation
WSLH	Wisconsin State Laboratory of Hygiene

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory (as appropriate) testing, collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF), in cooperation with the EPA, operates the Water Quality Protection Center (WQPC). The WQPC evaluated the performance of the Downstream Defender®, a stormwater treatment device designed to remove suspended solids, and other stormwater pollutants from wet weather runoff.

It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the Testing Organization (TO).

1.2 Testing Participants and Responsibilities

The ETV testing of the Downstream Defender® was a cooperative effort among the following participants:

- U.S. Environmental Protection Agency
- NSF International
- U.S. Geologic Survey (USGS)
- Wisconsin Department of Natural Resources (WDNR)
- Wisconsin State Laboratory of Hygiene (WSLH)
- USGS Sediment Laboratory
- Earth Tech, Inc.
- Hydro International

The following is a brief description of each ETV participant and their roles and responsibilities.

1.2.1 U.S. Environmental Protection Agency

The EPA Office of Research and Development, through the Urban Watershed Branch, Water Supply and Water Resources Division, National Risk Management Research Laboratory (NRMRL), provides administrative, technical, and quality assurance guidance and oversight on all ETV Water Quality Protection Center activities. In addition, EPA provides financial support for operation of the Center and partial support for the cost of testing for this verification.

The key EPA contact for this program is:

Mr. Ray Frederick, ETV WQPC Project Officer
(732) 321-6627
email: Frederick.Ray@epamail.epa.gov

U.S. EPA, NRMRL
Urban Watershed Management Research Laboratory
2890 Woodbridge Avenue (MS-104)
Edison, New Jersey 08837-3679

1.2.2 Verification Organization

NSF is the verification organization (VO) administering the WQPC in partnership with EPA. NSF is a not-for-profit testing and certification organization dedicated to public health, safety, and protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF name, logo and/or mark meet those standards.

NSF personnel provided technical oversight of the verification process. NSF also provided review of the test plan and this verification report. NSF's responsibilities as the VO include:

- Review and comment on the test plan;
- Review quality systems of all parties involved with the TO, and qualify the TO;
- Oversee TO activities related to the technology evaluation and associated laboratory testing;
- Conduct an on-site audit of test procedures;
- Provide quality assurance/quality control (QA/QC) review and support for the TO;
- Oversee the development of the verification report and verification statement; and
- Coordinate with EPA to approve the verification report and verification statement.

Key contacts at NSF are:

Mr. Thomas Stevens, P.E. Program Manager (734) 769-5347 email: stevenst@nsf.org	Mr. Patrick Davison Project Coordinator (734) 913-5719 email: davison@nsf.org

NSF International
789 North Dixboro Road
Ann Arbor, Michigan 48105

1.2.3 Testing Organization

The TO for the verification testing was Earth Tech, Inc. of Madison, Wisconsin (Earth Tech), with assistance from USGS in Middleton, Wisconsin. USGS provided testing equipment, helped to define field procedures, conducted the field testing, coordinated with the analytical laboratories, and conducted initial data analyses.

The TO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The TO was responsible for ensuring that the testing location and conditions allowed for the verification testing to meet its stated objectives. The TO prepared the test plan; oversaw the testing; and managed, evaluated, interpreted and reported on the data generated during the testing, as well as evaluated and reported on the performance of the technology. TO employees set test conditions, and measured and recorded data during the testing. The TO's Project Manager provided project oversight.

The key personnel and contacts for the TO are:

Earth Tech:

Mr. Jim Bachhuber, P.H.
(608) 828-8121
email: jim_bachhuber@earthtech.com

Earth Tech, Inc.
1210 Fourier Drive
Madison, Wisconsin 53717

USGS:

Ms. Judy Horwatich
(608) 821-3874
email: jahorwat@usgs.gov

USGS
8505 Research Way
Middleton, Wisconsin 53562

1.2.4 Analytical Laboratories

The WSLH, located in Madison, Wisconsin, analyzed the stormwater samples for the parameters identified in the test plan. The USGS Sediment Laboratory, located in Iowa City, Iowa, performed the particle size analysis on the material removed from the Downstream Defender® sump at the end of the monitoring period. All other suspended sediment concentration separations and particle size analyses were conducted by WSLH.

The key analytical laboratory contacts are:

Mr. George Bowman
(608) 224-6279
email: gtb@mail.slh.wisc.edu

WSLH
2601 Agriculture Drive
Madison, Wisconsin 53718

Ms. Pam Smith
(319) 358-3602
email: pksmith@usgs.gov

USGS Sediment Laboratory
Federal Building Room 269
400 South Clinton Street
Iowa City, Iowa 52240

1.2.5 Vendor

The Downstream Defender® is designed by Hydro International, US headquartered in Portland, Maine. Hydro International was responsible for providing technical support, and was available during the tests to provide technical assistance as needed.

The key contact for Hydro International is:

Mr. Kwabena Osei
(207) 756-6200
kosei@hil-tech.com

Hydro International
94 Hutchins Drive
Portland, ME 04102

1.3 System Owner/Operator

A 6-ft diameter Downstream Defender® was installed at the Madison Water Utility at 119 East Olin Avenue, Madison Wisconsin.

The key contact for the Madison Water Utility is:

Mr. Alan Larson
608-266-4651
allarson@madisonwater.org

Madison Water Utility
119 East Olin Avenue
Madison, WI 53713

Bureau of Environment
Wisconsin Department of Transportation
4802 Sheboygan Avenue, Room 451
Madison, Wisconsin 53707

Chapter 2
Technology Description

The following technology description data was supplied by the vendor and does not represent verified information.

2.1 Treatment System Description

The information provided in this section was provided by the vendor and has not been verified by the TO. The information is a generic description of the product being tested and is not specific to the Madison Water Utility site.

The Downstream Defender® is an advanced hydrodynamic vortex separator designed to remove settleable solids (and their associated pollutants), oil, and floatables from stormwater runoff. Its flow-modifying internal components have been developed from extensive full-scale testing, computational fluid dynamics modeling and over thirty years of hydrodynamic separation experience in wastewater, combined sewer, and stormwater applications. The internal components distinguish the Downstream Defender® from simple swirl-type devices and conventional oil/grit separators by minimizing turbulence and headlosses, enhancing separation, and preventing re-suspension of previously stored pollutants.

The Downstream Defender® has no moving parts and no external power requirements. It consists of a cylindrical concrete vessel, with plastic internal components and a 304 stainless steel support frame and connecting hardware. The concrete vessel is a standard pre-cast cylindrical manhole with a tangential inlet pipe installed below ground. Two ports at ground level provide access for inspection and clean out of stored floatables and sediment. The internal components consist of two concentric hollow cylinders (the dip plate and center shaft), an inverted cone (the center cone), a benching skirt, and a floatables lid. The Downstream Defender's® key components are illustrated in Figure 2-1.

The Downstream Defender® is self-activating, and operates on simple fluid dynamics. The geometry of the internal components and placement of the inlet and outlet pipes are designed to direct the flow in a pre-determined path through the vessel.

Stormwater is introduced tangentially into the side of the vessel, initially spiraling around the perimeter in the outer annular space between the dip plate cylinder and manhole wall. Oil and floatables rise to the water surface and are trapped by the dip plate in the outer annular space. As the flow continues to rotate about the vertical axis, it travels down towards the bottom of the dip plate. Low energy vortex motion directs sediment toward the center and base of the vessel. Flow passes under the dip plate and up through the inner annular space, between the dip plate and center shaft, as a narrower spiraling column rotating at a slower velocity than the outer downward flow.

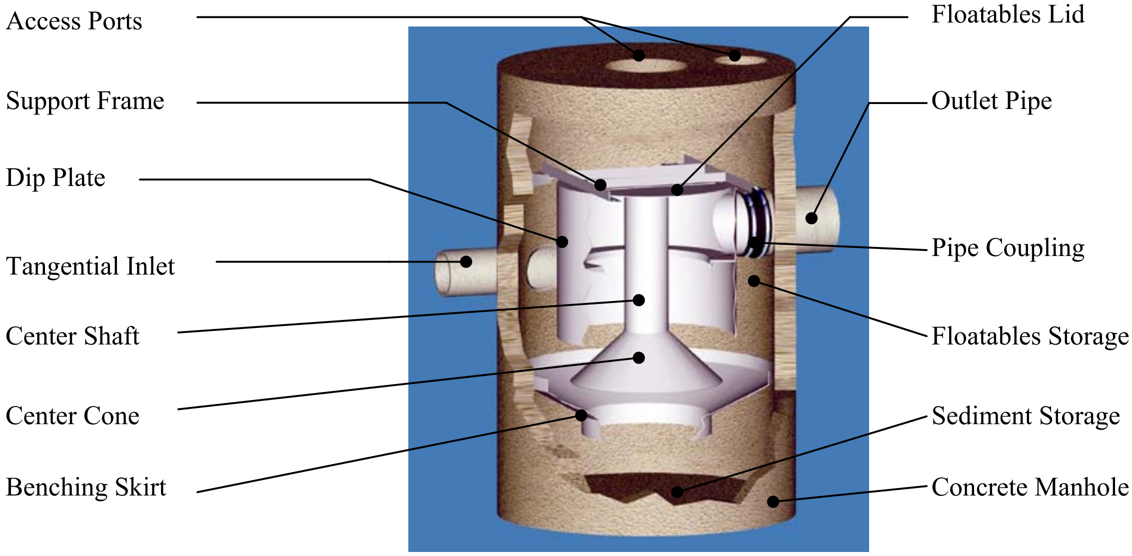


Figure 2-1. Downstream Defender® interior view (generic depiction).

The outlet of the Downstream Defender® is a single central discharge from the top water level in the inner annulus. Discharging from the inner annulus forces each fluid element to pass through a long spiral path from the inlet, downward through the outer annulus, then upward through the inner annulus before it can be released. This increases the retention time for the separation of settleable solids and floatables.

The Downstream Defender® is designed to collect accumulated pollutants outside the treatment flow path. This prevents re-entrainment into the effluent during major storms or surcharge conditions. Furthermore, removal and retention efficiencies are maintained because pollutants such as sediment, floatables, and oils accumulate between clean-outs and are collected and stored in isolated storage zones over a period of several months.

A section view of the Downstream Defender® is shown in Figure 2-2 to illustrate isolated pollutant storage locations and the purpose of the offset inlet and outlet inverts. The Downstream Defender® is designed with a submerged inlet. The crown of the inlet pipe where it connects to the unit is at the same elevation as the invert of the outlet pipe. The outlet pipe invert is placed on the hydraulic profile to maintain a static water level in the Downstream Defender® equal to the invert elevation of the outlet pipe. During a storm event, the submerged inlet introduces flow below the unit's static water surface, forcing floatables to rise into the outer annular region between the dip plate and concrete manhole. Submerging the inlet aids in stabilizing the flow regime over the unit's entire flow range. This enhances the removal efficiency and prevents re-suspension and washout (re-entrainment) of previously stored pollutants.

Headlosses of the Downstream Defender® are primarily a function of the inlet pipe diameter. The larger the inlet pipe diameter, the lower the headlosses. Headlosses can be decreased by increasing the inlet pipe diameter up to the diameter of the outlet pipe.

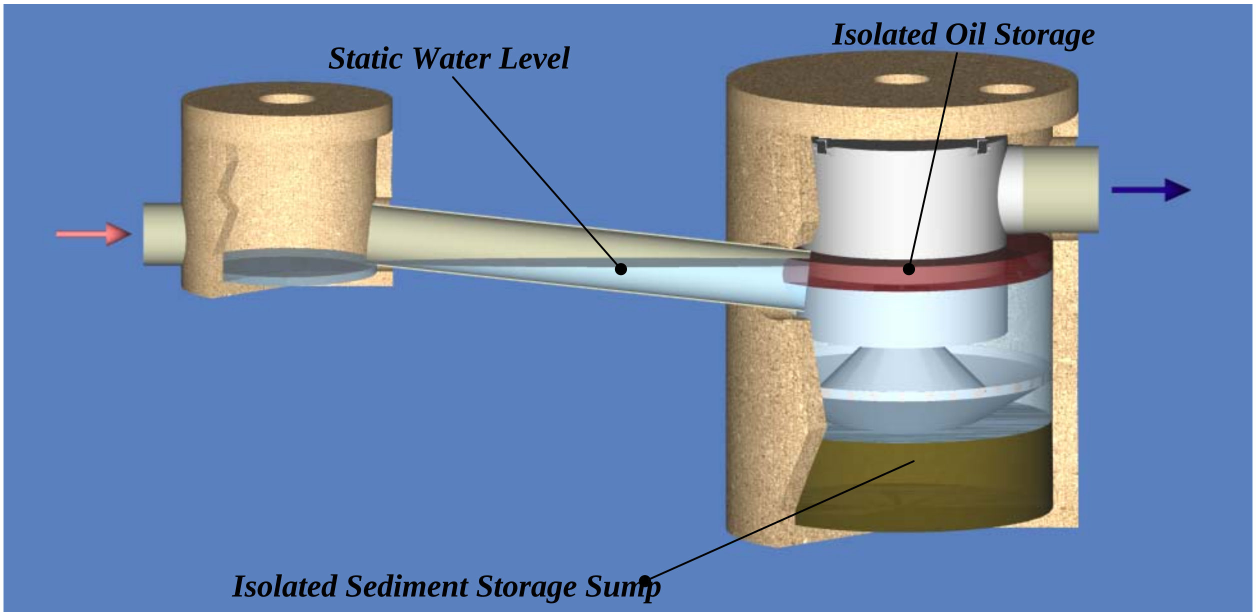


Figure 2-2. Downstream Defender® submerged inlet and isolated pollutant storage locations.

As the rotating flow spirals downward in the outer annular space, the benching skirt directs sediment toward the center and base of the vessel where it is collected in the sediment storage facility, beneath the vortex chamber. The center cone protects stored sediment and redirects the main flow upwards and inwards under the dip plate into the inner annular space. The dip plate is located at the shear zone (the interface between the outer downward circulation and the inner upward circulation where a marked difference in velocities encourages solids separation). A floatables lid covers the effluent area in the inner annular space between the dip plate and center shaft to keep oil and floatables stored in the outer annulus separate from the treated effluent. Figure 2-3 summarizes how the internal components of the Downstream Defender® address storing pollutants within the same vessel without compromising removal efficiencies due to re-suspension and/or washout (re-entrainment).

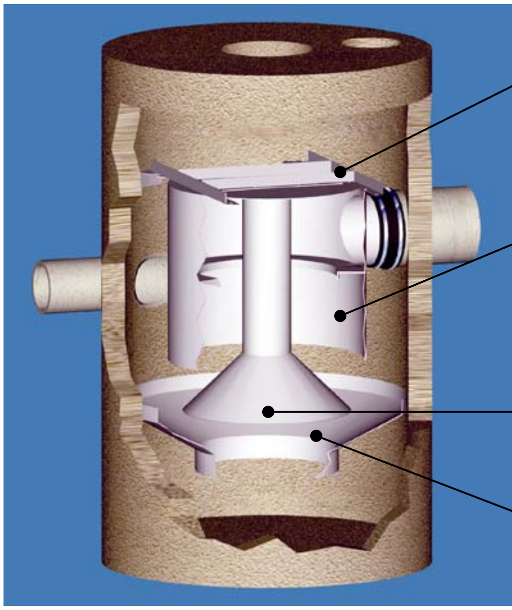


Figure 2-3. Downstream Defender® – internal components.

The Downstream Defender® can be used in the following applications:

- New developments and retrofits;
- Construction sites;
- Streets and roadways;
- Parking lots;
- Vehicle maintenance wash-down yards;
- Industrial and commercial facilities;
- Wetlands protection; and
- Pre-treatment for filter and other polishing systems.

The unit should be installed in a location that is easily accessible for a maintenance vehicle, preferably in a flat area close to a roadway or parking area.

2.2 Technology Description (site specific)

Specific information on the Downstream Defender® installed at the test site is presented in this section. All pipe sizes were measured by Earth Tech and USGS during an inspection trip on June 22, 2005. All pipe diameters are inside diameters. The field measured pipe diameters do not always match the sizes shown on Figures 2-4, 2-5, and 2-6. These differences may be for the following reasons:

- Some field measurements were very difficult to obtain because of the location of the pipe. The field measurements should be considered ±0.5 in.;

- The pipes' shapes may be deflected during the construction process and round pipes are now slightly different in shape; or
- The size pipe installed was not the same as the pipe size shown in the drawings.

A 6-ft diameter Downstream Defender® was installed at the Madison Water Utility site in the fall of 2004. Two clean out/access ports at grade level are located above the Downstream Defender®. A flow diversion structure is located approximately 13 ft north of the Downstream Defender®. Flow from the drainage area is received to the diversion structure through a 13.5-in. PVC inlet pipe. The Downstream Defender® has a 12-in. PVC inlet pipe and a 16.5-in. PVC outlet pipe. A weir in the diversion manhole has a crest elevation approximately 14 in. above the invert of the inlet pipe. The outlet pipe from the diversion manhole to the site's wet detention pond is 13 in. in diameter.

Figures 2-4, 2-5, and 2-6 detail the planned design for the Downstream Defender® at the Madison Water Utility site. The pipe diameters shown on the drawings are not consistent with diameters measured in the field. Elevations on the device and the inlet and outlet pipes that have been field verified (based on a survey conducted by Earth Tech in September, 2005) are indicted on Figure 2-4.

Additional equipment specifications, test site descriptions, testing requirements, sampling procedures, and analytical methods were detailed in the *Test Plan for the Verification of Downstream Defender "Madison Water Utility Administration Building Site" Madison, Wisconsin (September 30, 2005)*. The test plan is included in Appendix B.

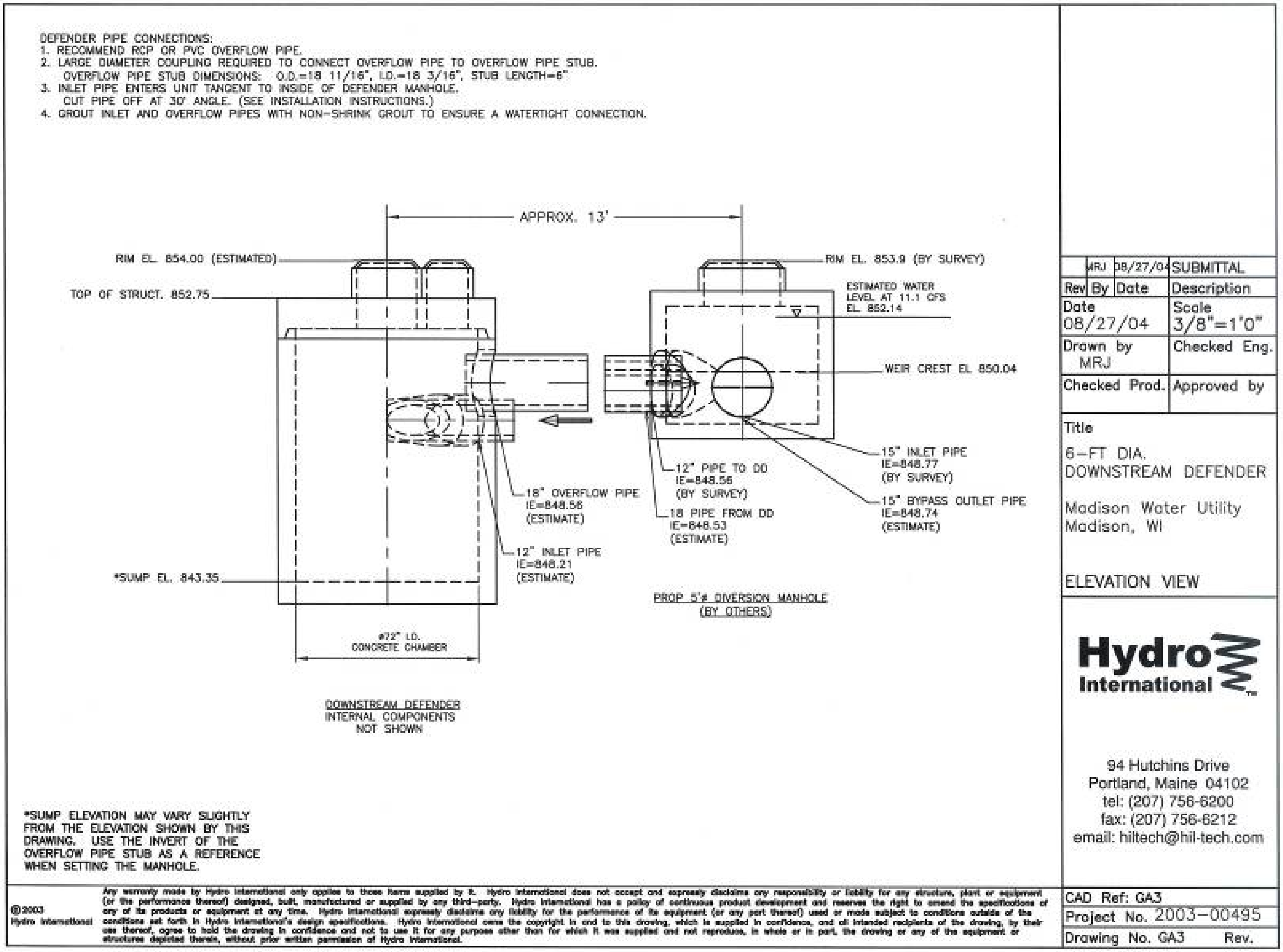


Figure 2-4. Elevation view of the Downstream Defender®

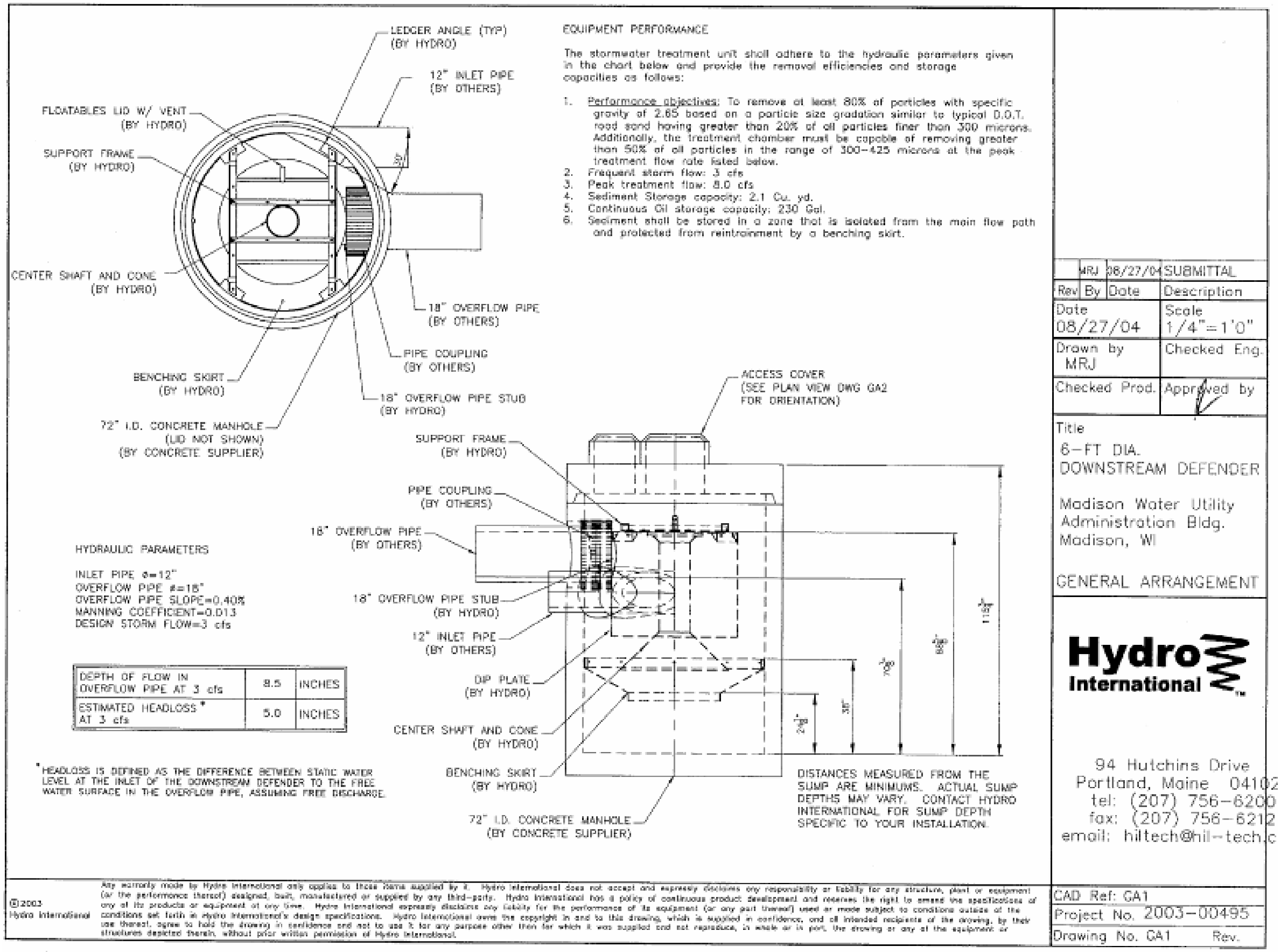


Figure 2-5. General arrangement of the Downstream Defender®, Madison, WI.

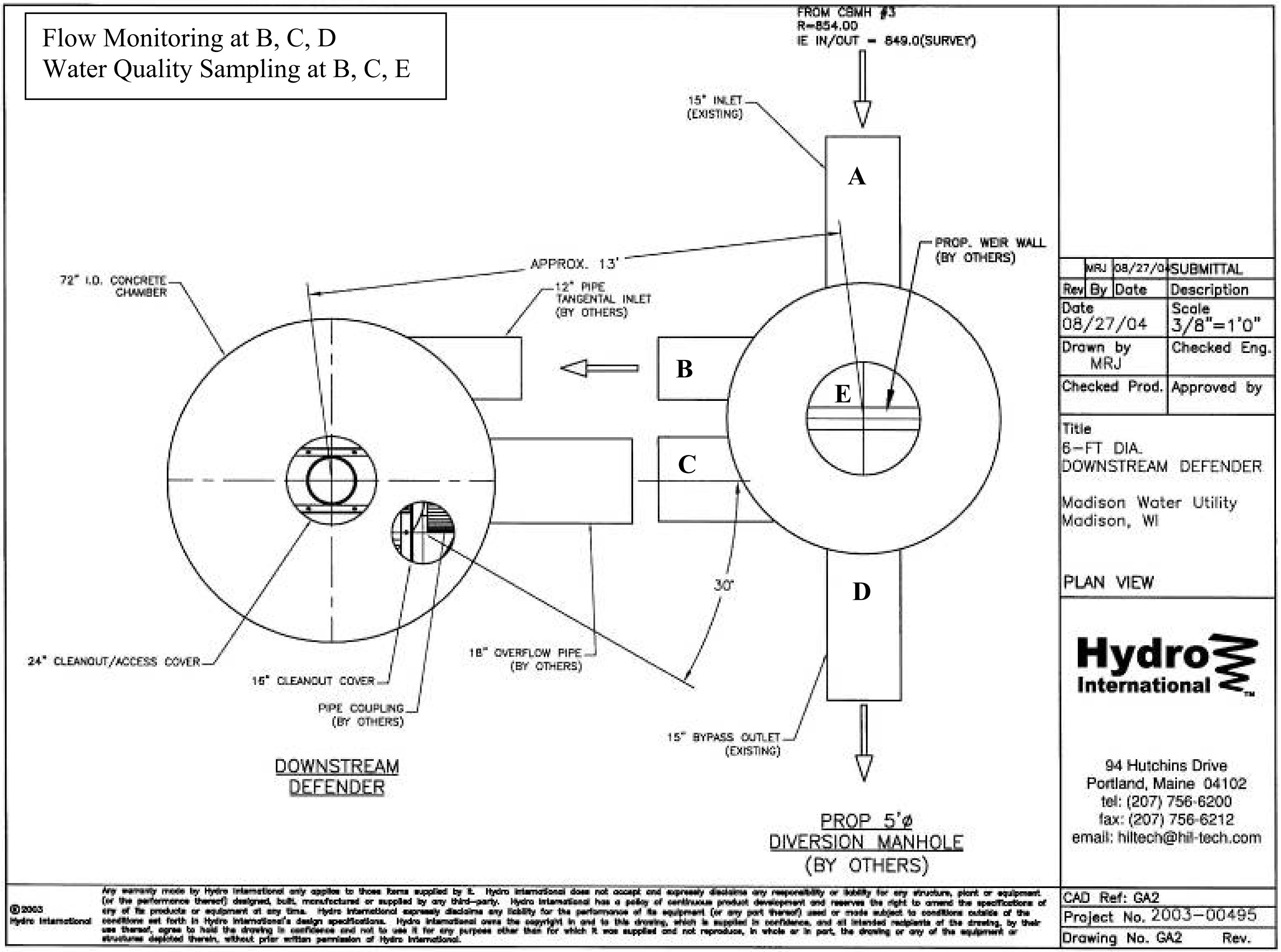


Figure 2-6. Plan view of the Downstream Defender®, Madison, WI.

2.3 Maintenance

Hydro International provided the following guidance and information on the operation and maintenance of the system.

The Downstream Defender® operates on simple fluid hydraulics. It is self-activating, has no moving parts, no external power requirement and is fabricated with durable non-corrosive components. Therefore, no procedures are required to operate the unit and maintenance is limited to monitoring accumulations of stored pollutants and periodic clean-outs. The Downstream Defender® has been designed to allow for easy and safe access for inspection/monitoring and clean-out procedures. Entry into the unit or removal of the internal components is not necessary for maintenance so that safety concerns related to confined-space-entry are avoided.

The internal components of the Downstream Defender® have been designed to protect the oil, floatables and sediment storage volumes so that treatment capacities are not reduced as pollutants accumulate between clean-outs. Additionally, the Downstream Defender® is designed and installed into the storm drain system so that the vessel remains wet between storm events. Oil and floatables are stored on the water surface in the outer annulus separate from the sediment storage volume in the sump of the unit providing the option for separate oil immobilization, removal and disposal (such as the use of absorbent pads). Since the oil/floatables and sediment storage volumes are isolated from the active separation region, the potential for re-suspension and washout of stored pollutants between clean-outs is minimized.

Keeping the unit wet also prevents stored sediment from solidifying in the base of the unit. The clean-out procedure becomes much more difficult and labor intensive if a stormwater treatment system allows fine sediment to dry-out and consolidate. When this occurs, clean-out crews must enter the chamber and manually remove the sediment; a labor intensive operation in a potentially hazardous environment.

A sump-vacuum is used to remove captured sediment and floatables. Access ports are located in the top of the manhole. The floatables access port is above the area between the concrete manhole wall and the dip plate. The sediment removal access port is located directly over the hollow center shaft. The frequency of the sump vacuum procedure is determined in the field after installation. During the first year of operation, the unit should be inspected every six months to determine the rate of sediment and floatables accumulation. A simple probe can be used to determine the level of solids in the sediment storage facility. This information can be recorded in maintenance logs to establish a routine maintenance schedule. Maximum pollutant storage capacities are provided in Table 2-1. To prevent floatables and oils from entering the sediment sump storage volume, it is recommended that oil and floatables are removed prior to removing sediment.

Table 2-1. Downstream Defender® Pollutant Storage Capacities and Maximum Clean-out Depths

Unit Diameter (ft)	Total Oil Storage (gal)	Oil Clean-Out Depth (in.)	Total Sediment Storage (gal)	Sediment Clean-Out Depth (in.)	Total Volume Removed (gal)
4	70	< 16	141	< 18	384
6	230	< 23	424	< 24	1,240
8	525	< 33	939	< 30	2,890
10	1,050	< 42	1,760	< 36	5,550

Maintenance records were maintained during testing and are included in Chapter 7.

2.4 Performance Claim

This section was prepared by Hydro International.

The following are performance claims made by Hydro International regarding the Downstream Defender® stormwater quality treatment unit installed at the Madison Water Utility Administration Building Site in Madison, WI.

The Downstream Defender® is designed to remove and prevent washout (re-entrainment) of settleable solids and floatables from stormwater runoff. In addition, with proper maintenance, treatment capacities are not reduced as pollutants accumulate between clean-outs.

2.4.1 Total Suspended Solids

The 6-ft Downstream Defender® installed at the Madison Water Utility Administration Building Site is designed to remove settleable solids from stormwater runoff. Generally, the removal efficiency of the Downstream Defender® decreases with increasing flow rates, finer particles and cooler water temperatures. For runoff at 15 C°, the Downstream Defender® will remove over 80% of settleable solids with a specific gravity of 2.65 with a particle size distribution similar to Maine DOT road sand (see Figure 2-7) at flow rates up to 3 cfs (see Figure 2-8). Hydro International defines "settleable sediment" as particles greater than 62 µm in size.

Performance of the Downstream Defender®, in terms of sediment removals, depends on the incoming flow rate, particle size distribution, specific gravity and runoff temperature. Figure 2-7 shows two example particle size distributions (for Maine DOT road sand and F-110 silica sand).

The range of removals for each particle size distribution based on flow are shown in Figure 2.8 (assuming a water temperature of 15° C).

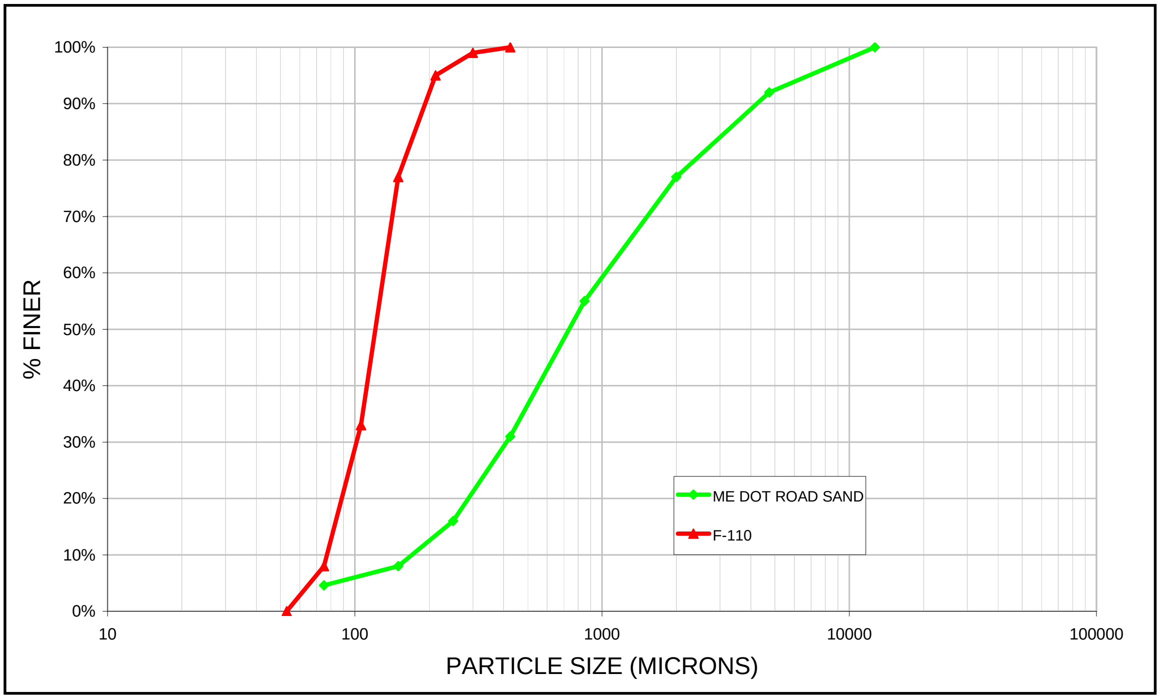


Figure 2-7. Particle size distribution for ME DOT road sand and F-110 silica sand.

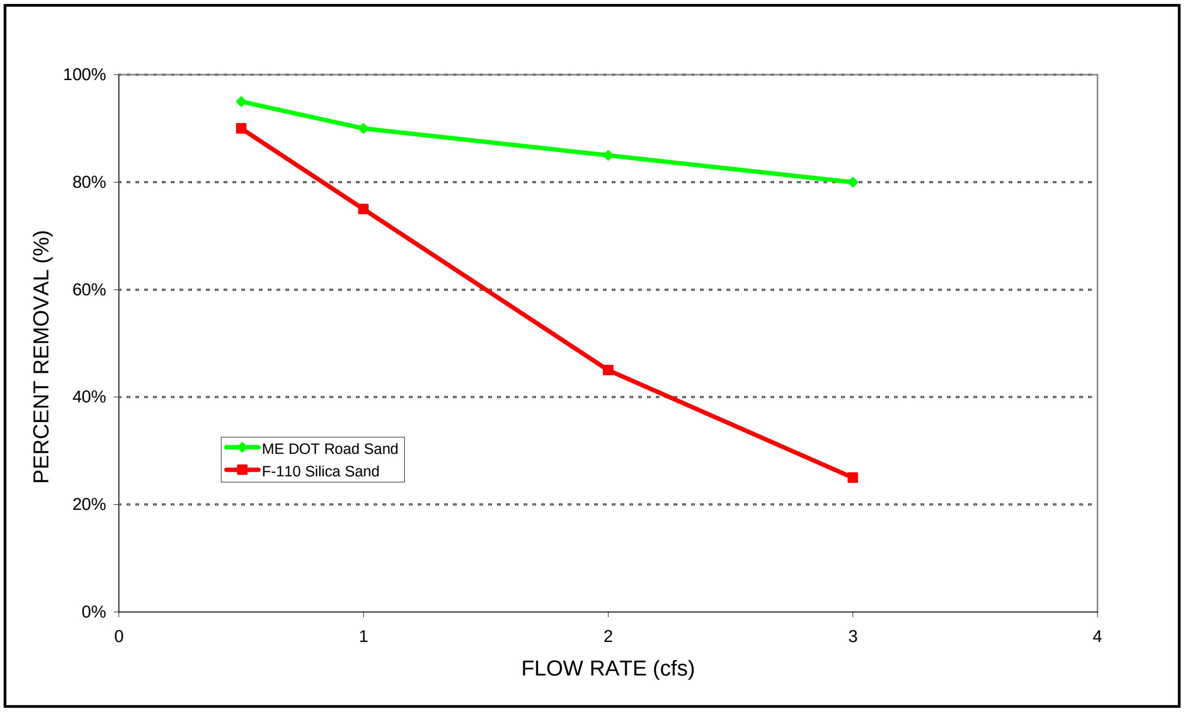


Figure 2-8. Removal efficiencies for differing sediment gradations at 15 °C.

2.4.2 Metals and Nutrients

Significant levels of metals and nutrients have been detected in the sediment removed by the Downstream Defender® during tests conducted at other locations. Removal of metals and nutrients depends on the portion of these contaminants that are attached to the particulates. Therefore, no specific removal claims are made.

2.4.3 Hydrocarbons

Even though the Downstream Defender® is designed to treat petroleum hydrocarbons in stormwater, Hydro International did not make specific performance claims for petroleum hydrocarbons to be verified by ETV testing, and this test plan will not include provisions to verify the Downstream Defender® hydrocarbon treatment capability.

2.4.4 Floatables

Up to 100% floatables removal has been observed visually in the Downstream Defender®. However, the ETV protocol has no provisions for monitoring floatables. Therefore, no specific performance claims are made.

Chapter 3
Test Site Description

3.1 Location and Land Use

The Downstream Defender® is located in the parking lot at the Madison Water Utility Administration Building at 119 East Olin Avenue in Madison, Wisconsin. The latitude and longitude coordinates are 43° 3'9" N and 89° 22'55" W. The device receives direct stormwater runoff from the parking lot and rooftops through a storm sewer collection system. Figure 3-1 shows the location of the test site.

The Madison Water Utility Building grounds cover about 5.5 acres. Figure 3-2 shows the site conditions with the drainage area and storm sewer collection system delineated. Based on the analysis conducted during the Test Plan development, the drainage area tributary to the device was 1.9 acres in size. Table 3-1 shows a breakout of the land uses within the drainage area. based on that analysis.

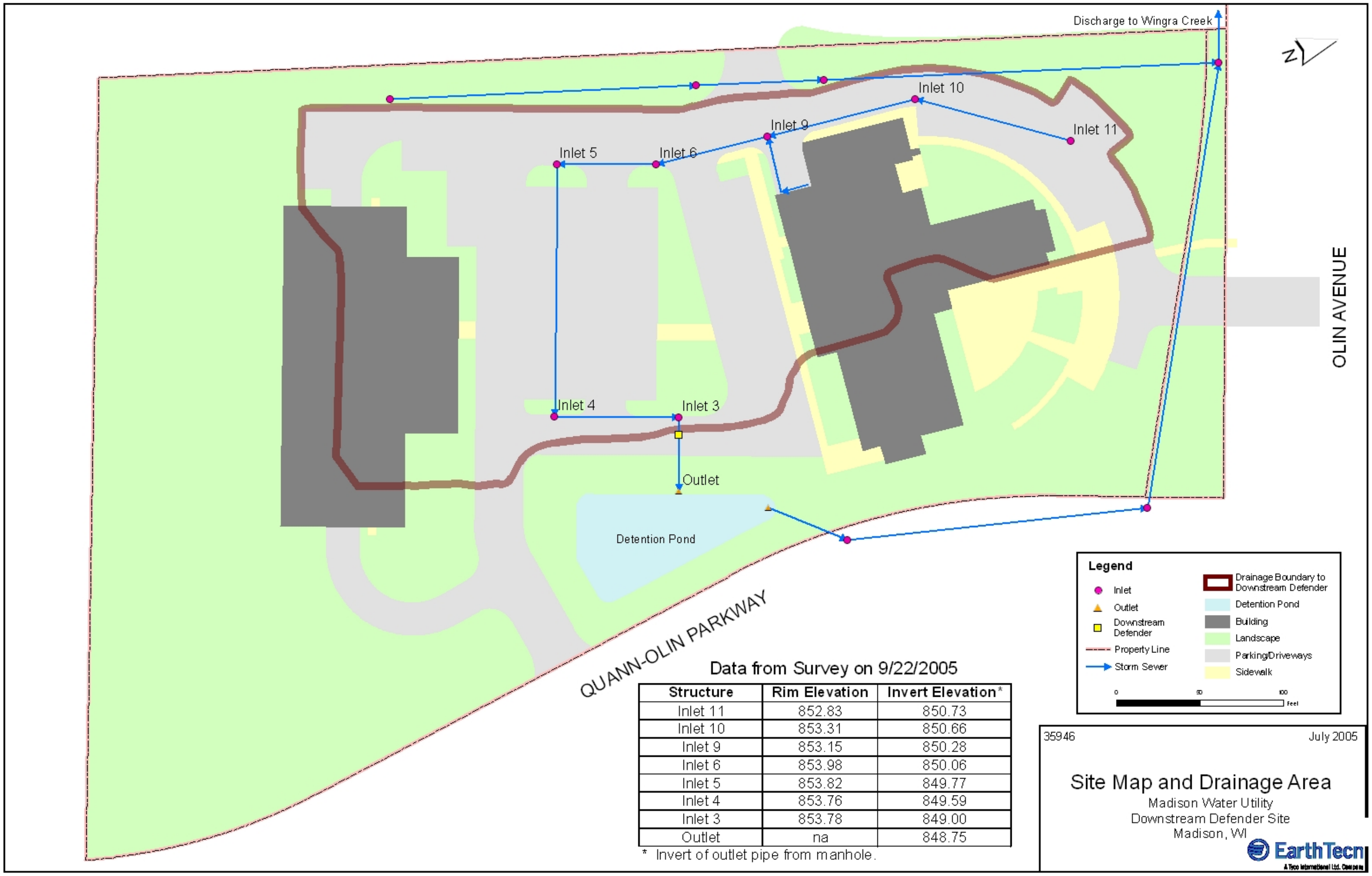
Table 3-1. Drainage Area Land Use

	Walkways/ Sidewalks	Parking Lot/ Road	Building (Roof)	Landscape	Total Area
Area (acres)	0.08	1.05	0.49	0.29	1.91

The property adjacent to the Madison Water Utility (to the west) is a City of Madison recycling facility with outside storage of yard and brush waste. Visual inspection (during the Test Plan development phase) indicated that some runoff from this property could enter the monitored area. The City of Madison constructed a speed bump diversion (shown in Figure 3-3) to keep this runoff from entering the monitored area.

During the monitoring phase, evidence indicated that during certain larger events, runoff from the recycling facility may have overtopped the speed bump (see Figure 3-3), contributing additional runoff to the monitored drainage area, especially during large storm events. Based on a site inspection conducted by Earth Tech and the WDNR, the extent of the additional drainage area size could be as much as four acres. It cannot be precisely determined how much additional runoff is contributed to the monitored area for the following reasons: 1) various intensities and rain depths will likely jump the installed "speed bump"; 2) a depressed inlet to the south of the driveway between the two properties was intermittently clogged and a certain portion of the runoff would be stored at this location before additional runoff would enter into the monitored drainage area. See Section 6.2.3 of this report for further discussion of this issue.

Figure 3-1. Site location.



Data from Survey on 9/22/2005

Structure	Rim Elevation	Invert Elevation*
Inlet 11	852.83	850.73
Inlet 10	853.31	850.66
Inlet 9	853.15	850.28
Inlet 6	853.98	850.06
Inlet 5	853.82	849.77
Inlet 4	853.76	849.59
Inlet 3	853.78	849.00
Outlet	na	848.75

* Invert of outlet pipe from manhole.

Figure 3-2. Site map and drainage area.

(a) **(b)**

Figure 3-3. (a) Diversion between test site and adjacent side (b) evidence of overtopping after runoff event.

3.2 Pollutant Sources and Site Maintenance

The main pollutant sources within the drainage area are created by vehicular traffic, rooftop drainage, atmospheric deposition, and, winter sand or rock salt that is applied as conditions require.

The storm sewer catch basins do not have sumps. There are no other stormwater best management practice (BMP) devices within the drainage area.

3.3 Stormwater Conveyance System

The site is drained by a storm sewer collection system. The storm sewer system within the monitored drainage system consists of 12- and 15-in. diameter concrete pipe. The storm sewer collects stormwater from the buildings and parking lot and conveys it to the Downstream Defender®. From the Downstream Defender®, the treated stormwater (and bypass flow) enters a wet detention pond (located at the Water Utility property) and subsequently to the city's storm sewer system.

The storm sewer collection system that conveys stormwater to the Downstream Defender® and the bypass structure, was surveyed on September 22, 2005 by Earth Tech. Surface elevations and pipe invert elevations for the inlets were measured. Measurements were also taken at the flow diversion manhole of the Downstream Defender®. The City of Madison provided benchmark elevations on the site. The benchmark used for the survey was located on the top of the fire hydrant on the west edge of the site and it has an elevation of 856.47 ft. The survey results for the storm sewer system are shown on Figure 3-2.

Based on the survey results there was a concern that backwater from the detention pond could create a tailwater effect on the bypass structure's outlet pipe (location D on Figure 2-6). To reduce the potential for this occurrence the pond's low flow outlet opening was enlarged in the fall of 2005 (for the monitoring period). There were no issues noted with any of the runoff events resulting from the modification to the outlet pipe.

An 18 in. storm sewer along the north edge of the site, collects runoff from part of the main building, parking lot and landscaped areas, and discharges directly to Wingra Creek. This system does not discharge runoff to the monitored drainage area.

3.4 Water Quality/Water Resources

The receiving water of the site's runoff is Wingra Creek, which is a tributary to Lake Monona. Wingra Creek is on the WDNR 303(d) impaired waters list. Wingra Creek's impairments are aquatic toxicity and contaminated sediment.

Most of the urban communities within the Yahara watershed including the City of Madison are under the State of Wisconsin stormwater permitting program (NR 216). This program meets or exceeds the requirements of EPA's Phase I stormwater regulations.

3.5 Local Meteorological Conditions

Madison, Wisconsin has the typical continental climate of interior North America with a large annual temperature range and with frequent short period temperature changes. Madison experiences cold snowy winters, and warm to hot summers. Average annual precipitation is approximately 33 in., with an average annual snowfall of 44 in. Additional details on temperature and precipitation records are included in the Test Plan.

Chapter 4
Sampling Procedures and Analytical Methods

Descriptions of the sampling locations and methods used during verification testing are summarized in this section. Additional detail may be found in the test plan.

4.1 Sampling Locations

The detailed locations of the flow and water quality sampling locations are shown in Figure 2.6. Below is a description of each site identified in Figure 2.6:

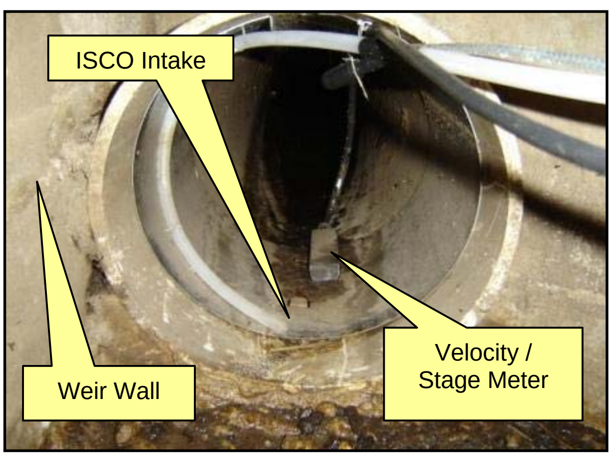
Site A: This site conveys all of the raw stormwater from the drainage area to the flow splitting device. No flow or water quality monitoring occurred at this site.

Site B: This is the inlet to the Downstream Defender®. At this site both a velocity/stage sensor and a water quality sampling line were established.

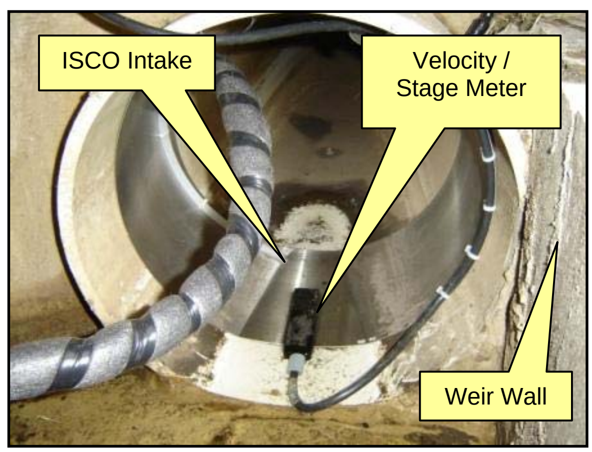
Site C: This is the outlet from the Downstream Defender®. At this site both a velocity/stage sensor and a water quality sampling line were established.

Site D: This is the system outlet site. All stormwater both treated and untreated (overflow bypass at Site E) pass out this pipe. At this location a velocity / stage sensor is located.

Site E: This is the high-flow bypass weir. Discharge greater than 3 cfs (the design flow for the treatment system) is bypassed over the weir. At this site a water quality sampling line was established. The sampling line was fixed at the top of the weir wall and samples were only taken when flow overtopped the weir elevation.

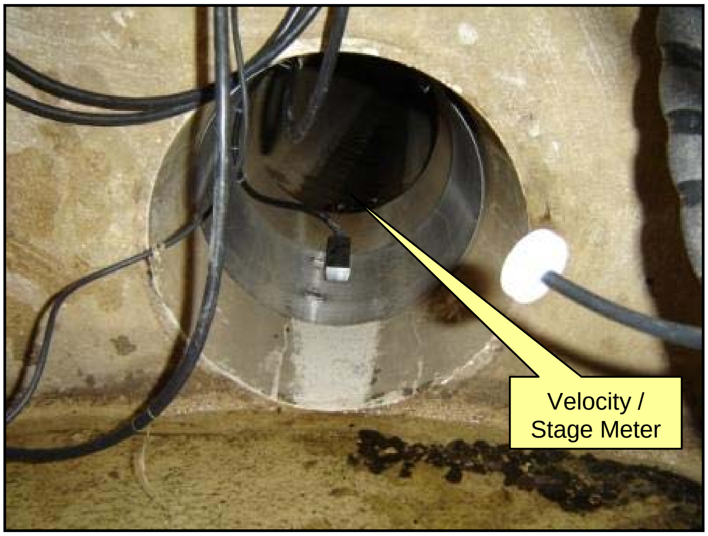


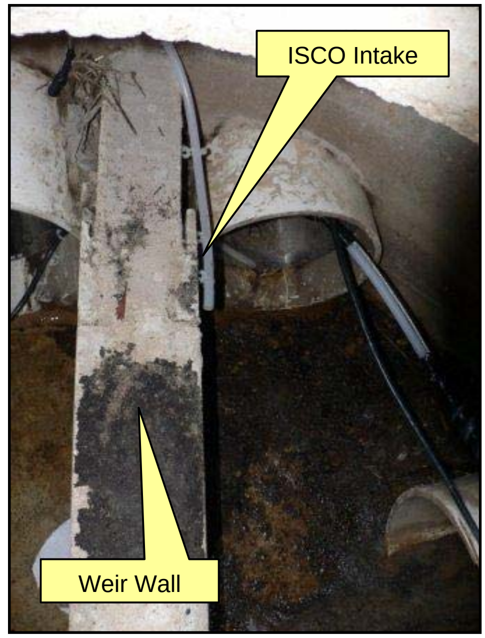
Site B



Site C

Figure 4-1. Monitoring equipment for sites B and C.





Site D **Site E**

Figure 4-2. Monitoring equipment for sites D and E.

4.2 Other Monitoring Locations

A rain gauge was located adjacent to the drainage area to monitor the depth and intensity of precipitation from storm events. The data were used to characterize the events to determine if they met the requirements for a qualified storm event.

4.3 Monitoring Equipment

The specific equipment used for monitoring flow, sampling water quality, and measuring rainfall for the upstream and downstream monitoring points are listed in Table 4-1.

Table 4-1. Monitoring Equipment

Location	Velocity / Stage	Water Quality Sampling	Other
Site B	ISCO 2150 flow meter	ISCO 3700 with ¾ in. Teflon™ sample tube	
Site C	ISCO 2150 flow meter	ISCO 3700 with ¾ in. Teflon™ sample tube	
Site D	ISCO 2150 flow meter		
Site E		ISCO 3700 with ¾ in. Teflon™ sample tube	
Flow Splitter Chamber			Stage & Temperature: Design Analysis H-310 Pressure Transducer & Temperature Probe
Sampling Station		ISCO 3700 refrigerated automatic samplers (3)	Data Logger: Campbell Scientific, Inc. CR10X Modem: Campbell Scientific COM 200
Rain Gauge			Design Analysis H340SPI tipping bucket rain gauge

4.4 Contaminant Constituents Analyzed

The list of constituents analyzed in the stormwater samples is shown in Table 4-2. The vendor's performance claim addresses reductions of inorganic sediments from the runoff water.

The TSS analytical method utilized for this project was modified using a process developed by USGS (Selbig, 2007). The modification is intended to more accurately quantify the concentration of larger sediment particles in a sample. An explanation of the modified method is found in Appendix A. For the purposes of this report, the TSS concentrations are reported as "adjusted TSS" concentrations to reflect the possible differences in concentrations between the USGS method and the strict adherence to the USEPA method 160.2.

4.5 Sampling Schedule

USGS personnel installed the monitoring equipment under a contract with the WDNR. The monitoring equipment was installed in September, 2005. Several trial events were monitored and equipment was tested in the Fall of 2005. The first qualified event was successfully monitored in April, 2006. The last qualified event was monitored in August of 2006. Table 4-3 summarizes the sample collection data from the storm events.

Table 4-2. Constituent List for Water Quality Monitoring

Parameter	Reporting Units	Limit of Detection	Limit of Quantification	Method[1]
Total dissolved solids (TDS)	mg/L	50	167	SM 2540C
Total suspended solids (TSS)[2]	mg/L	2	7	EPA 160.2
Volatile suspended solids (VSS)	mg/L			
Suspended sediment concentration (SSC)	mg/L	0.1	0.5	ASTM D3977-97
Sand-silt split	NA	NA	NA	Fishman *et al.*
Five point sedigraph	NA	NA	NA	Fishman *et al.*
Sand fractionation	NA	NA	NA	Fishman *et al.*

1 EPA: *EPA Methods and Guidance for the Analysis of Water* procedures; SM: *Standard Methods for the Examination of Water and Wastewater (19th edition)* procedures; ASTM: American Society of Testing and Materials procedures; Fishman et al.: *Approved Inorganic and Organic Methods for the Analysis of Water and Fluvial Sediment* procedures.

2 *Explanation of TSS Analysis*: In Chapter 5 of this document all TSS results are reported as "Adjusted TSS" values. A full explanation of the procedures and reasoning for the adjustments is provided in Appendix A.

The 20 storm events listed in Table 4-3 met the requirements of a "qualified event," as defined in the test plan:

- The total rainfall depth for the event, measured at the site rain gauge, was 0.2 in. (5 mm) or greater;
- Flow through the treatment device was successfully measured and recorded over the duration of the runoff period;
- A flow-proportional composite sample was successfully collected for both the inlet and outlet (and bypass if applicable) over the duration of the runoff event;
- Each composite sample collected was comprised of a minimum of five aliquots, including at least two aliquots on the rising limb of the runoff hydrograph, at least one aliquot near the peak, and at least two aliquots on the falling limb of the runoff hydrograph; and
- There was a minimum of six hours between qualified sampling events.

Table 4-3. Summary of Events Monitored for Verification Testing

	System Inlet Sampling Point (Site B)					Unit Outlet Sampling Point (Site C)					System Outlet Sampling Point (Site E)				
Event Number	Start Date	Start Time[1]	End Date	End Time[1]	No. of Aliquots	Start Date	Start Time[1]	End Date	End Time[1]	No. of Aliquots	Start Date	Start Time[1]	End Date	End Time[1]	No. of Aliquots
1	3/8/06	18:03	3/9/06	0:45	18	3/8/06	18:09	3/8/06	22:51	40					
2	3/12/06	18:34	3/13/06	4:23	12	3/12/06	22:29	3/13/06	3:40	16					
3	4/2/06	20:41	4/3/06	6:47	22	4/2/06	20:43	4/3/06	6:58	22					
4	4/12/06	5:07	4/12/06	8:01	19	4/12/06	5:11	4/12/06	8:38	19					
5	4/16/06	4:15	4/16/06	16:33	39	4/16/06	4:23	4/16/06	16:24	39	4/16/06	13:04	4/16/06	13:20	8
6	4/29/06	17:18	4/30/06	17:11	43	4/29/06	16:51	4/30/06	10:50	42					
7	5/1/06	21:16	5/1/06	22:05	15	5/1/06	21:17	5/1/06	22:18	14					
8	5/9/06	12:01	5/9/06	18:01	20	5/9/06	14:25	5/9/06	20:00	16					
9	5/11/06	6:59	5/12/06	5:40	31	5/11/06	7:11	5/12/06	2:02	27					
10	5/17/06	15:36	5/17/06	17:14	10	5/17/06	15:38	5/17/06	16:38	10					
11	6/25/06	17:34	6/26/06	8:15	26	6/25/06	17:47	6/26/06	7:47	25					
12	7/9/06	19:45	7/9/06	20:55	11	7/9/06	19:45	7/9/06	20:26	12					
13	7/11/06	8:44	7/11/06	14:47	40	7/11/06	8:48	7/11/06	13:47	40					
14	7/19/02	21:43	7/20/02	7:11	23	7/20/02	2:50	7/20/02	7:25	24					
15	7/22/06	16:51	7/22/06	17:40	11	7/22/06	16:51	7/22/06	17:41	12					
16	7/27/06	12:27	7/27/06	14:37	30	7/27/06	12:29	7/27/06	13:20	30	7/27/06	12:32	7/27/06	13:23	34
17	8/6/06	6:53	8/6/06	11:05	20	8/6/06	6:59	8/6/06	11:22	21					
18	8/17/06	16:27	8/17/06	17:26	8	8/17/06	16:30	8/17/06	17:11	8					
19	8/23/06	23:06	8/24/06	7:26	30	8/23/06	23:07	8/24/06	6:58	30	8/24/06	3:37	8/24/06	3:45	10
20	8/24/06	13:30	8/25/06	6:27	29	8/24/06	13:29	8/25/06	7:20	33	8/24/06	13:31	8/25/06	15:07	32

1. Time of first and last water quality sample from the event.

Table 4-4 summarizes the rainfall data for the qualified events. Detailed information on each storm's runoff hydrograph and the rain depth distribution over the event period are included in Appendix C.

Table 4-4. Rainfall Summary for Monitored Events

Event Number	Rainfall Depth (in.)	Rainfall Duration (hr:min)	Runoff Volume (ft^3) Site B	Site E	Peak Flow Rate[4] (cfs)	Temp (°C)
1	0.71	4:36	1,880		1.0	3.5
2	0.43	9:25	1,370		0.42	4.6
3	1.01	10:01	5,910		0.38	15.5
4	0.37	2:56	1,980		0.63	--[2]
5	1.13	12:44	6,230	1,240	5.8[1]	--[2]
6	1.65	25:38	8,480		0.66	--[2]
7	0.25	0:26	1,570		2.0	--[2]
8	0.37	6:50	2,090		0.35	15.4[3]
9	0.86	23:55	5,040		0.18	10.5[3]
10	0.23	2:02	1,310		0.85	14.8[3]
11	0.79	15:41	4,250		0.67	19.0[3]
12	0.36	0:08	1,430		2.6	24.8[3]
13	1.87	8:51	10,990		1.5	20.7[3]
14	0.96	9:44	4,680		2.5	22.8[3]
15	0.36	0:30	1,860		1.9	23.0[3]
16	2.16	1:30	7,150	7,720	6.5[1]	24.0[3]
17	0.71	5:08	3,630		0.50	23.4[3]
18	0.29	1:45	1,300		1.3	22.4[3]
19	1.60	8:17	13,450	1,220	4.4[1]	22.4[3]
20	1.35	2:13	17,180	3,720	4.6[1]	22.8[3]

1. Peak design flow rate exceeded during event.
2. Temperature not recorded because of equipment malfunction.
3. Temperature readings were recorded from a nearby stormwater monitoring site. See Section 6.3 for details.
4. Peak flow rate as measured at the system outlet pipe (Site D)

The Downstream Defender® was sized to treat a maximum flow rate of 3 cfs. The high-flow weir elevation within the flow-splitter structure was set so that flow rates in excess of 3 cfs was diverted over the weir and bypassed the Downstream Defender®. When flow exceeded approximately 3 cfs, the sampling line at location E was activated and flow-weighted water quality samples of the bypass water were collected.

4.6 Field Procedures for Sample Handling and Preservation

Data gathered by the on-site datalogger were accessible to USGS personnel by means of a modem and phone-line hookup. USGS personnel collected samples and performed a system inspection after storm events.

Water samples were collected with ISCO automatic samplers programmed to collect 1-L aliquots during each sample cycle. A peristaltic pump in the sampler pumped water from the sampling location through Teflon™-lined sample tubing to the pump head where water passed through approximately three feet of silicone tubing and into one of four 10-L sample collection bottles. Samples were capped and removed from the sampler after the event by the USGS personnel. The samples were then transported to the USGS field office in Middleton Wisconsin, where they were split into multiple aliquots using a 20-L Teflon™-lined churn splitter. When more than 20 L (two 10-L sample collection bottles) of sample were collected by the autosamplers, the contents of the two full sample containers would be poured into the churn, a portion of the sample in the churn would be discarded, and a proportional volume from the third or fourth sample container would be poured into the churn. The analytical laboratories provided sample bottles. Samples were preserved per method requirements and analyzed within the holding times allowed by the methods.

The samples were maintained in the custody of the sample collectors, delivered directly to the laboratory, and relinquished to the laboratory sample custodian(s). Custody was maintained according to the laboratory's sample handling procedures. To establish the necessary documentation to trace sample possession from the time of collection, field forms and lab forms (see Appendix B of the test plan) were completed and accompanied each sample.

Chapter 5
Monitoring Results and Discussion

The verification testing results related to contaminant reduction are reported in two formats:

1. Efficiency ratio comparison, which evaluates the effectiveness of the system for each qualified storm event on an event mean concentration (EMC) basis.

2. Sum of loads (SOL) comparison, which evaluates the effectiveness of the system for all qualified storm events on a constituent mass (concentration times volume) basis.

The test plan required that only various forms of solids, be evaluated to test the vendor's performance claim.

5.1 Monitoring Results: Performance Parameters

5.1.1 Concentration Efficiency Ratio

The concentration efficiency ratio reflects the treatment capability of the device using the event mean concentration (EMC) data obtained for each runoff event. The concentration efficiency ratios are calculated by:

$$\text{Efficiency ratio} = 100 \times (1-[EMC_{outlet}/EMC_{inlet}]) \qquad (5\text{-}1)$$

The inlet and outlet sample concentrations and calculated efficiency ratios are summarized by analytical parameter categories.

The inlet, outlet, and bypass sample concentrations and calculated efficiency ratios for sediment parameters are summarized in Table 5-1. As noted in Section 4.4, the TSS method utilized for this project was based on a procedure developed by USGS (Selbig, 2007) and intended to provide a more accurate methodology for quantification of larger sediment particles. For the purposes of this report, these values are reported as "adjusted TSS" values. The raw data used to calculate the adjusted TSS concentrations are summarized in Tables 5-3, 5-4, and 5-5. The adjusted TSS inlet concentrations ranged from 23 to 700 mg/L, the outlet concentrations ranged from 19 to 584 mg/L, and the efficiency ratio ranged from -51 to 62%. The SSC inlet concentrations ranged 22 to 904 mg/L, the outlet concentrations ranged from 21 to 662 mg/L, and the efficiency ratio ranged from -47 to 70%.

The TDS inlet concentrations ranged from <50 to 260 mg/L, the outlet concentrations ranged from <50 to 238 mg/L, and the efficiency ratio ranged from –163 to 55%. The highest TDS inlet and outlet concentrations occurred during events 1 and 2 in the spring. The high concentrations may be the result of residual road salt being washed off the pavement.

Table 5-1. Monitoring Results and Efficiency Ratios for Sediment Parameters

	TSS (adjusted)				SSC				TDS				VSS			
Event No.	DD Inlet (mg/L)	DD Outlet (mg/L)	System Outlet (mg/L)	Reduction (%)[1]	DD Inlet (mg/L)	DD Outlet (mg/L)	System Outlet (mg/L)	Reduction (%)[1]	DD Inlet (mg/L)	DD Outlet (mg/L)	System Outlet (mg/L)	Reduction (%)[1]	DD Inlet (mg/L)	DD Outlet (mg/L)	System Outlet (mg/L)	Reduction (%)[1]
1	126	147	NA	-17	127	166	NA	-31	260	238	NA	8	26	38	NA	-46
2	62	52	NA	16	64	52	NA	19	192	86	NA	55	13	15	NA	-15
3	59	36	NA	39	58	36	NA	38	96	84	NA	13	NA	NA	NA	--
4	121	97	NA	20	120	95	NA	21	74	86	NA	-16	20	19	NA	5
5	227	188	675	17	270	190	1006	30	62	94	<50	-52	28	45	65	-61
6	35	30	NA	14	35	30	NA	14	54	56	NA	-4	22	18	NA	18
7	144	217	NA	-51	165	202	NA	-22	<50	64	NA	<-28	47	69	NA	-47
8	23	24	NA	-4	22	21	NA	5	74	52	NA	30	12	11	NA	8
9	24	19	NA	21	25	22	NA	12	88	60	NA	32	16	13	NA	19
10	159	153	NA	4	156	143	NA	8	58	66	NA	-14	70	61	NA	13
11	106	105	NA	1	104	104	NA	0	60	52	NA	13	52	49	NA	6
12	395	584	NA	-48	450	662	NA	-47	80	72	NA	10	49	72	NA	-47
13	35	38	NA	-9	57	37	NA	35	<50	<50	NA	--	9	10	NA	-11
14	81	120	NA	-49	128	137	NA	-7	52	<50	NA	>4	20	30	NA	-50
15	103	119	NA	-16	116	127	NA	-9	<50	<50	NA	--	21	24	NA	-14
16	700	425	534	41	904	418	610	54	96	82	94	15	33	37	46	-12
17	51	37	NA	27	59	37	NA	37	<50	58	NA	<-16	26	18	NA	31
18	544	207	NA	62	705	211	NA	70	78	98	NA	-26	46	73	NA	-59
19	447	348	401	22	527	327	476	38	136	112	90	18	58	61	66	-5
20	483	292	424	39	624	285	494	54	226	222	170	2	76	76	67	0

1. Percent reduction values based on difference of DD Inlet and DD Outlet .

Table 5-2. Adjusted TSS Calculations for Downstream Defender® Inlet

	Sieved Sediments (mg/L) Sieve Size (Contribution to Sum)			Adjusted TSS Concentration (mg/L)		
Event No.[1]	500 µm (70%)	250 µm (55%)	125 µm (60%)	Sum Product of Sieved Concentration	Aqueous Concentration	Sieved + Aqueous Concentration
2	0.5	1.1	4.5	3.7	58	62
5	0.5	92	30	69	158	227
12	0.5	94	44.0	78.6	316	395
16	472	101	54.3	419	281	700
18	502	21.3	26.3	379	165	544
19	225	18.8	29.7	186	261	447
20	0.5	291	56.6	195	288	483

1. Events listed are limited to those where the adjusted TSS method was utilized.

Table 5-3. Adjusted TSS Calculations for Downstream Defender® Outlet

	Sieved Sediments (mg/L) Sieve Size (Contribution to Sum)			Adjusted TSS Concentration (mg/L)		
Event No.	500 µm (70%)	250 µm (55%)	125 µm (60%)	Sum Product of Sieved Concentration	Aqueous Concentration	Sieved + Aqueous Concentration
12	0.5	71.3	178	146	438	584
16	54.5	20.7	61.6	86.5	338	425
19	7.2	8.6	48.9	39.1	310	349

1. Events listed are limited to those where the adjusted TSS method was utilized.

Table 5-4. Adjusted TSS Calculations for System Outlet

	Sieved Sediments (mg/L) Sieve Size (Contribution to Sum)			Adjusted TSS Concentration (mg/L)		
Event No.	500 µm (70%)	250 µm (55%)	125 µm (60%)	Sum Product of Sieved Concentration	Aqueous Concentration	Sieved + Aqueous Concentration
5	1	133	124	148	527	675
16	185	73	58	205	329	534
19	62	24	52	87	314	401
20	115	45	29	123	301	424

1. Events listed are limited to those where system outlet samples were collected and the adjusted TSS method was utilized.

The VSS inlet concentrations ranged from 9 to 76 mg/L, the outlet concentrations ranged from 11 to 76 mg/L, and the efficiency ratio ranged from –59 to 19%. VSS is a measure of organic material, such as leaves or grass clippings, which generally have a specific gravity lower than inorganic sediments. Both organic and inorganic sediments are measured as part of the TSS or SSC analytical methods. A comparison of VSS to TSS or SSC gives an approximate percentage of organic sediments as part of the total sediment concentrations or loadings.

The Downstream Defender® operates as a hydrodynamic separator. Particles with a comparatively higher density or specific gravity are retained by the unit, while particles with a lower density or specific gravity tend to pass through the unit. Table 5-5 shows the ratio of VSS concentrations to adjusted TSS and SSC concentrations for the inlet and outlet concentrations for each event (except event 3, in which VSS samples were not analyzed). The contribution of organic sediments would reduce the sediment specific gravity, and thus the effectiveness of the Downstream Defender® to remove sediments.

Table 5-5. Ratio of Organic Sediment Concentrations to Total Sediment Concentrations

	Inlet Ratios		Outlet Ratios	
Event No.	VSS/TSS (%)	VSS/SSC (%)	VSS/TSS (%)	VSS/SSC (%)
1	21	20	26	23
2	21	20	29	29
4	17	17	20	20
5	12	10	24	24
6	63	63	60	60
7	33	28	32	34
8	52	55	46	52
9	67	64	68	59
10	44	45	40	43
11	49	50	47	47
12	12	11	12	11
13	26	16	26	27
14	25	16	25	22
15	20	18	20	19
16	4.7	3.7	8.9	8.9
17	51	44	49	49
18	8.5	6.5	35	35
19	13	11	18	19
20	16	12	26	27
Median	21	18	26	27
Minimum	4.7	3.7	8.9	8.9
Maximum	67	64	68	60

5.1.2 *Sum of Loads*

The sum of loads (SOL) is the sum of the percent load reduction efficiencies for all the events, and provides a measure of the overall performance efficiency for the events sampled during the monitoring period. The load reduction efficiency is calculated using the following equation:

$$\% \text{ Load Reduction Efficiency} = 100\times(1-(A/B)) \qquad (5\text{-}2)$$

where:
A = Sum of Outlet Load = (Outlet EMC_1)(Flow $Volume_1$) + (Outlet EMC_2)(Flow $Volume_2$) + (Outlet EMC_n)(Flow $Volume_n$)
B = Sum of Inlet Load = (Inlet EMC_1)(Flow $Volume_1$) + (Outlet EMC_2)(Flow $Volume_2$) + (Outlet EMC_n)(Flow $Volume_n$)
n= number of qualified sampling events

Flow was monitored in the Downstream Defender® inlet (site B), Downstream Defender® outlet (site C), and the system outlet (site D). For the purposes of SOL calculations, the inlet flow data was used to calculate both the Downstream Defender® inlet and Downstream Defender® outlet SOL values. Flow at site D was used to calculate SOL values of the overall system as further described below.

The SOL values are calculated for:

1. The load change between site B and site C. This represents the actual sediment changes for the stormwater that only entered and exited the Downstream Defender®;

2. The load change between site A and site D. This represents the sediment load changes of the overall system (total raw stormwater runoff);

3. The SOL was also calculated by particle size (sand/silt split). Since all events were analyzed by SSC, and a particle distribution was conducted for each event, the analysis could be conducted. (see Table 5-3 for these results).

Sediment: Tables 5-6 and 5-7 summarizes results for the SOL calculations for each sediment analyte (adjusted TSS, SSC, TDS, and VSS).

Hydro International's performance claim is repeated below:

> "For runoff at 15 C°, the Downstream Defender® will remove over 80% of settleable solids with a specific gravity of 2.65 with a particle size distribution similar to Maine DOT road sand at flow rates up to 3 cfs. Hydro International defines "settleable sediment" as particles greater than 62 µm in size."

Each of the conditions mentioned in the performance claim are summarized below:

- *Water Temperature*: Based on the temperature data shown in Table 4-4, the water temperature of all except for events 1, 2, and 9 were at or above 15 C°.

- *Specific Gravity:* Specific gravity of the sediment captured in the sampler was not required, based on the test plan. However, the test plan required that specific gravity of the sediment samples captured in the sump of the Downstream Defender® be measured. However, based on the data presented in Table 5-2, the contribution of organic sediments to the total sediment load would reduce the specific gravity of the captured sediments. The measured specific gravity of sediment samples from the Downstream Defender® sump was less than 2.0. Typical inorganic sediments have a specific gravity ranging from 2.5 to 3.0. This finding would indicate the presence of lighter organic sediments retained in the sump.

- *Flow:* The data in Table 4-4 show that bypass occurred only in events where the peak flow exceeded 3 cfs. This indicates that the weir wall elevation was properly set to bypass flows greater than 3 cfs around the Downstream Defender®. The maximum peak recorded flow was 5.61 cfs. The average observed peak flow for all events was 1.9 cfs.

- *Particle Size Distribution:* Particle size distribution was measured for each event. The results of this analysis are shown in Table 5-8. The particle size distribution was also used to summarize the SOL results by particle size in Table 5-9. This table shows how much load was captured by the Downstream Defender® for each particle size and for the "cumulative" particle size. For example, based the results shown in Table 5-10; the Downstream Defender® captured 67% of the sediment particles greater than 63 µm (of the loading that actually entered the Downstream Defender®) and 58% of the sediment particles greater than 63 µm (of the loading that entered the flow splitter).

Table 5-6. Sediment Sum of Loads Results (adjusted TSS and SSC)

Event No.	Inlet Runoff Volume (ft^3)	Adjusted TSS DD Inlet (lb)	Adjusted TSS DD Outlet (lb)	Adjusted TSS DD bypass (lb)	Adjusted TSS System Outlet (lb)	SSC DD Inlet (lb)	SSC DD Outlet (lb)	SSC DD bypass (lb)	SSC System Outlet (lb)
1	1,880	15	17		15	15	20		15
2	1,370	5	4		5	6	4		6
3	5,910	22	13		22	22	13		22
4	1,980	15	12		15	15	12		15
5	6,230	89	74	52	141	106	74	77	183
6	8,480	19	16		19	19	16		19
7	1,570	14	21		14	16	20		16
8	2,090	3	3		3	3	3		3
9	5,040	8	6		8	8	7		8
10	1,310	13	13		13	13	12		13
11	4,250	28	28		28	28	28		28
12	1,430	35	53		35	40	60		40
13	10,990	24	26		24	39	26		39
14	4,680	24	35		24	38	40		38
15	1,860	12	14		12	14	15		14
16	7,150	315	191	259	574	406	188	296	702
17	3,630	12	8		12	13	8		13
18	1,300	44	17		44	58	17		58
19	13,450	378	295	31	409	446	276	37	482
20	17,180	521	315	99	620	674	308	116	789
Sum of Loads		1,596	1,163	441	2,037	1,977	1,147	525	2,502
Reduction efficiency (%)		27%[1]		22%[2]		42%[1]		33%[2]	

1. Reduction efficiency only for load entering and exiting the Downstream Defender® (does not account for bypass).
2. Reduction efficiency for entire load entering the bypass chamber and exiting the bypass chamber (accounts for bypass).

5.2 Particle Size Distribution

Particle size distribution analysis was completed on all events. In order to produce particle size distribution data, USGS sieved each sample with a 500 µm, 250 µm, and 125 µm sieve from a known volume of sample. The retained sediment was dried and weighed from a known volume of water (sample volume). The dried sediment weight and sample volume was used to calculate a sediment concentration at these three particle sizes. WSLH conducted a similar sieve analysis on the aqueous sample received from the USGS except that the WSLH sieved at 500 µm, 250 µm, 125 µm, 63 µm, and 32 µm size. A laser particle counter was used for particle size distribution smaller than 32 µm. The USGS and WSLH results are combined to report the final particle size concentrations and distributions for each event. Each particle size concentration is multiplied by the event volume to get an event load by particle size.

The particle size distribution results are summarized in Table 5-8. In each event, the outlet samples had a higher percentage of particles in the silt category (≤62.5 µm) than the equivalent inlet sample. This is a result of the separation treatment mechanism of the Downstream Defender® removing a higher percentage of the larger, heavier sediment particles.

Figure 5-1 is a comparison of the average inlet particle size distribution presented in Table 5-8 to the particle size distribution related to the vendor's performance claim, which was based on F-110 graded silica sand (see Figure 2-7). This comparison shows that the Downstream Defender® encountered a proportion of fine material greater than the anticipated material in their performance claim. For particles approximately 105 µm and smaller, the Downstream Defender® exceeded its performance claim.

Table 5-7. Sediment Sum of Loads Results (TDS and VSS)

		TDS				VSS			
Event No.	**Inlet Runoff Volume (ft^3)**	**DD Inlet (lb)**	**DD Outlet (lb)**	**DD Bypass (lb)**	**System Outlet (lb)**	**DD Inlet (lb)**	**DD Outlet (lb)**	**DD Bypass (lb)**	**System Outlet (lb)**
1	1,880	31	28		31	3	4		3
2	1,370	17	7		17	1	1		1
3	5,910	36	31		36	--	--		--
4	1,980	9	11		9	2	2		2
5	6,230	24	37	2	26	11	18	5	16
6	8,480	29	30		29	12	10		12
7	1,570	2	6		2	5	7		5
8	2,090	10	7		10	2	1		2
9	5,040	28	19		28	5	4		5
10	1,310	5	5		5	6	5		6
11	4,250	16	14		16	14	13		14
12	1,430	7	6		7	4	6		4
13	10,990	17	17		--	6	7		6
14	4,680	15	40		15	6	9		6
15	1,860	3	3		--	2	3		2
16	7,150	43	37	46	89	15	17	22	37
17	3,630	6	13		--	6	4		6
18	1,300	6	8		6	4	6		4
19	13,450	115	95	7	122	49	52	5	54
20	17,180	244	240	40	284	82	82	16	98
Sum of Loads		663	655		731	235	251		283
Reduction efficiency (%)		1%[1]			1%[2]	-7%[1]			-6%[2]

1. Reduction efficiency only for load entering and exiting the Downstream Defender® (does not account for bypass)
2. Reduction efficiency for entire load entering the bypass chamber and exiting the bypass chamber (accounts for bypass)

Table 5-8. Particle Size Distribution Analysis Results

Event No.	Location	Percent Less Than Particle Size (µm)								
		<500	<250	<125	<62.5	<31	<16	<8	<4	<2
1	Inlet (site B)	100	99	95	93	88	74	65	48	17
1	Outlet (site C)	100	97	96	93	88	70	59	42	9
2	Inlet (site B)	99	98	91	90	81	59	49	35	11
2	Outlet (site C)	99	98	96	92	86	76	63	46	12
3	Inlet (site B)	99	98	96	88	79	57	47	32	9
3	Outlet (site C)	99	98	95	92	86	66	56	40	12
4	Inlet (site B)	100	97	94	79	70	50	39	28	7
4	Outlet (site C)	99	98	94	83	71	50	40	29	7
5	Inlet (site B)	100	64	53	42	34	24	19	15	4
5	Outlet (site C)	100	81	64	43	31	20	15	10	2
5	System Outlet (site E)	100	94	83	57	44	29	24	17	5
6	Inlet (site B)	98	84	66	41	28	21	19	16	6
6	Outlet (site C)	98	87	66	39	28	20	18	15	8
7	Inlet (site B)	100	94	79	50	36	23	17	12	4
7	Outlet (site C)	98	91	71	52	34	23	19	13	3
8	Inlet (site B)	97	95	77	55	44	33	29	24	8
8	Outlet (site C)	97	92	70	48	37	31	27	22	10
9	Inlet (site B)	93	81	66	55	46	40	37	33	15
9	Outlet (site C)	98	77	62	47	36	31	29	24	9
10	Inlet (site B)	87	74	61	43	32	22	18	13	4
10	Outlet (site C)	94	89	68	49	37	25	20	14	3
11	Inlet (site B)	93	80	61	39	29	25	21	17	8
11	Outlet (site C)	97	85	67	36	27	24	19	15	7
12	Inlet (site B)	100	76	65	44	27	25	16	12	6
12	Outlet (site C)	100	88	58	40	24	19	11	7	3
13	Inlet (site B)	93	89	81	56	37	29	22	16	9
13	Outlet (site C)	95	91	84	61	40	37	33	28	19
14	Inlet (site B)	100	56	44	28	18	14	12	11	8
14	Outlet (site C)	94	90	80	59	39	33	24	18	9
15	Inlet (site B)	89	86	79	54	36	35	32	26	13
15	System Outlet (site E)	69	57	47	35	30	29	25	19	10
15	Unit Outlet	89	83	62	40	29	29	26	22	9
16	Inlet (site B)	46	34	28	23	20	19	16	12	6
16	Outlet (site C)	87	81	66	51	45	43	37	28	13
17	Inlet (site B)	85	73	53	39	30	28	27	26	24
17	Outlet (site C)	98	91	74	52	38	34	31	29	23
18	Inlet (site B)	27	24	20	16	13	12	10	8	5
18	Outlet (site C)	100	92	73	54	44	36	27	21	14
19	Inlet (site B)	55	51	45	38	29	27	23	21	16
19	System Outlet (site E)	86	80	68	55	38	36	32	29	26
19	Unit Outlet (site C)	98	95	80	69	56	53	45	37	26
20	Inlet (site B)	100	49	39	34	29	27	22	14	5
20	System Outlet (site E)	74	64	57	51	45	42	32	20	7
20	Unit Outlet (site C)	100	96	86	74	63	61	51	35	13

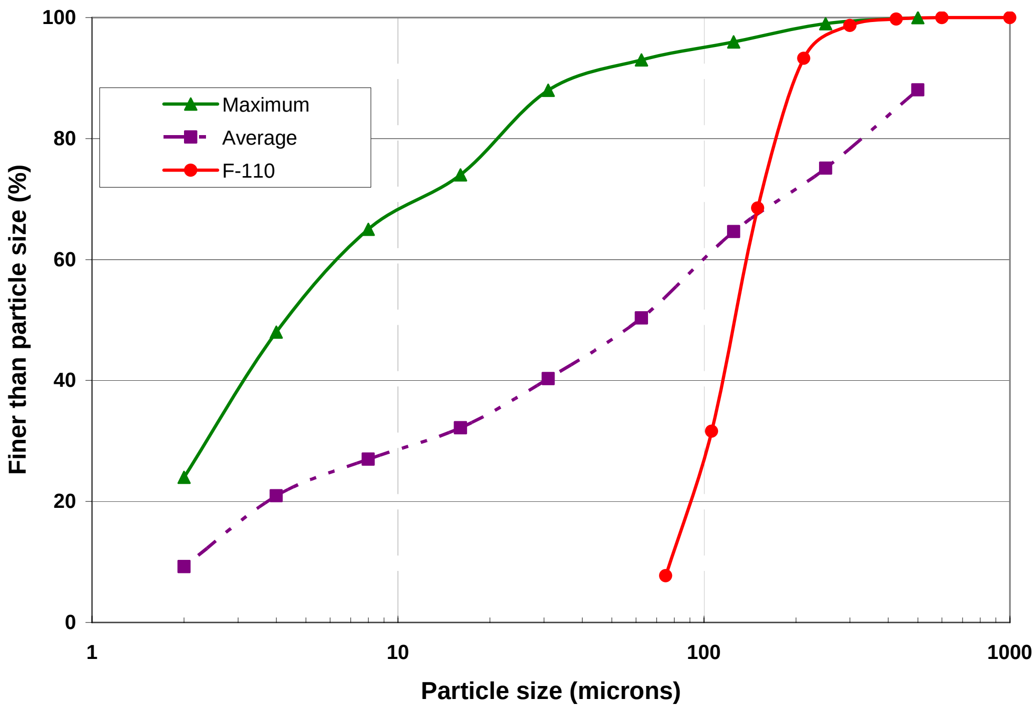


Figure 5-1. Average and maximum influent particle size distribution compared to vendor's performance claim based on F-110 silica sand.

The SOL can be recalculated for SSC concentrations and "sand/silt split" data to determine the proportion of sand and silt removed during treatment. This evaluation, summarized in Tables 5-9 and 5-10, shows that the Downstream Defender® was most effective in removing the larger particles. Particle size distribution is affected by such things as site conditions and land use, maintenance (e.g. street sweeping), and weather.

Table 5-9. Sediment Sum of Load Results by Particle Size Category – Individual Particle Size Load

Particle Size Category (µm)	DD Inlet (lb)	DD Outlet (lb)	Bypass (lb)	DD Efficiency (%)	System Efficiency (%)
> 500	453	39	32	91	85
250-500	449	49	58	89	79
125-250	150	146	49	3	2
63-125	128	156	56	-2	-15
32-63	122	122	31	0	0
32-14	517	550	164	-6	-5

Table 5-10. Sediment Sum of Load Results by Particle Size Category – Cumulative Particle Size Load

Particle Size Category (µm)	DD Inlet (lb)	DD Outlet (lb)	Bypass (lb)	DD Efficiency (%)	System Efficiency (%)
> 500	453	39	32	91	85
250-500	902	87	90	90	82
125-250	1,052	233	139	78	69
63-125	1,181	389	195	67	58
32-63	1,303	512	226	61	52
32-14	1,820	1,060	391	42	34

Chapter 6
QA/QC Results and Summary

The Quality Assurance Project Plan (QAPP) in the test plan identified critical measurements and established several QA/QC objectives. The verification test procedures and data collection followed the QAPP. QA/QC summary results are reported in this section, and the full laboratory QA/QC results and supporting documents are presented in Appendix D.

6.1 Laboratory/Analytical Data QA/QC

6.1.1 Bias (Field Blanks)

Field blanks were collected at both the inlet and outlet samplers on two separate occasions to evaluate the potential for sample contamination through the entire sampling process, including automatic sampler, sample-collection bottles, splitters, and filtering devices. “Milli-Q” reagent water was pumped through the automatic sampler, and collected samples were processed and analyzed in the same manner as event samples. The first field blank was collected on October 4, 2005 (before event sample began). The second field blank was collected on May 8, 2006 (between events 7 and 8).

Results for the field blanks are shown in Table 6-1. All analyses were below the limits of detection (LOD). These results show a good level of contaminant control in the field procedures was achieved.

Table 6-1. Field Blank Analytical Data Summary

		Blank 1 (10/04/05)			Blank 2 (5/08/06)				
Parameter	Units	Inlet	Unit Outlet	System Outlet	Inlet	Unit Outlet	System Outlet	LOD	LOQ
TSS	mg/L	<2	<2	<2	<2	<2	<2	2	7
SSC	mg/L	<2	<2	<2	<2	<2	<2	2	7
TDS	mg/L	<50	<50	<50	<50	<50	<50	50	167
VSS	mg/L	<2	<2	<2	<2	<2	<2	2	7

6.1.2 Replicates (Precision)

Precision measurements were performed by the collection and analysis of duplicate samples. The relative percent difference (RPD) recorded from the sample analyses was calculated to evaluate precision. RPD is calculated using the following formula:

$$\%RPD = \left(\frac{|x_1 - x_2|}{\bar{x}} \right) \times 100\% \qquad (6\text{-}1)$$

where:
x_1 = Concentration of compound in sample
x_2 = Concentration of compound in duplicate
$\bar{x}$ = Mean value of x_1 and x_2

Field precision: Field duplicates were collected to monitor the overall precision of the sample collection procedures. Duplicate inlet and outlet samples were collected during two different storm events to evaluate precision in the sampling process and analysis. A third field duplicate sampling was inadvertently missed. The duplicate samples were processed, delivered to the laboratory, and analyzed in the same manner as the regular samples. Summaries of the field duplicate data are presented in Table 6-2.

Overall, the results show very good field precision. The following section is a discussion on the results from selected parameters.

TSS, SSC, TDS, and VSS: Results were within targeted limits. Both inlet and outlet samples showed equally good precision, except for the outlet sample on 6/25/06 which had a 14% relative difference. This is still well within the precision objective of 30% (Table 6-1 of the Test Plan).

Table 6-2. Field Duplicate Relative Percent Difference Data Summary

				4/12/06			**6/25/06**	
Parameter	**Units**		**Rep 1a**	**Rep 1b**	**RPD (%)**	**Rep 1a**	**Rep 1b**	**RPD (%)**
TDS	mg/L	Inlet	74	76	3	60	56	7
		Outlet	86	84	2	52	56	7
TSS	mg/L	Inlet	121	119	2	106	105	--
		Outlet	97	98	1	105	105	0
SSC	mg/L	Inlet	120	120	0	104	105	1
		Outlet	95	94	1	104	102	2
VSS	mg/L	Inlet	20	20	0	52	52	0
		Outlet	19	19	0	49	51	4

Laboratory precision: WSLH analyzed duplicate samples from aliquots drawn from the same sample container as part of their QA/QC program. Summaries of the laboratory duplicate data are presented in Table 6-3.

Table 6-3. Laboratory Duplicate Sample Relative Percent Difference Data Summary

Parameter[1]	Count[2]	Mean (%)	Maximum (%)	Minimum (%)	Std. Dev. (%)
TSS	22	9.9	57	0	17
TDS	12	2.1	8	0	2.2
VSS	16	1.8	5.8	0	1.8

1 Laboratory precision may also be evaluated based on absolute difference between duplicate measurements when concentrations are low. For data quality objective purposes, the absolute difference may not be larger than twice the method detection limit.
2 Analyses where both samples were below detection limits were omitted from this evaluation.

6.1.3 Accuracy

Method accuracy was determined and monitored using laboratory control samples (known concentration in blank water). The laboratory control data were evaluated by calculating the absolute value of deviation from the laboratory control concentration. Accuracy was in control throughout the verification test. Tables 6-4 and 6-5 summarize the matrix spikes and lab control sample recovery data, respectively.

Table 6-4. Laboratory Control Sample Data Summary

Parameter	Count	Mean (%)	Maximum (%)	Minimum (%)	Std. Dev. (%)
SSC	9	2.8	4.9	0.29	1.3
TSS	20	6.7	21	0	5.7
TDS	13	5.1	14	0	4.3

The balance used for solids (TSS, TDS, and total solids) analyses was calibrated routinely with weights that were NIST traceable. The laboratory maintained calibration records. The temperature of the drying oven was also monitored using a thermometer that was calibrated with a NIST traceable thermometer.

6.1.4 Representativeness

The field procedures were designed to ensure that representative samples were collected of both inlet and outlet stormwater. Field duplicate samples and supervisor oversight provided assurance that procedures were being followed. The challenge in sampling stormwater is obtaining representative samples. The data indicated that while individual sample variability might occur, the long-term trend in the data was representative of the concentrations in the stormwater.

The laboratories used standard analytical methods, with written SOPs for each method, to provide a consistent approach to all analyses. Sample handling, storage, and analytical methodology were reviewed to verify that standard procedures were being followed. The use of standard methodology, supported by proper quality control information and audits, ensured that the analytical data were representative of actual stormwater conditions.

Regarding flow (velocity and stage) measurements, representativeness is achieved in three ways:

1. The meter was installed by experienced USGS field monitoring personnel familiar with the equipment, in accordance with the manufacturer's instructions;

2. The meter's individual area and velocity measurements were converted to a representation of the flow area using manufacturer's conversion procedures (see ISCO 2150 Area Velocity Flow Meter O&M Manual available from NSF International or Earth Tech);

3. The flow calculated from the velocity/stage measurements was calibrated using the procedure described in Section 6.2.

To obtain representativeness of the sub-samples (aliquots) necessary to analyze the various parameters from the event sample, a churn splitter was used. As noted in Radtke, et al. (1999), the churn splitter is the industry standard for splitting water samples into sub-samples. However, inconsistencies have been noted in the sub-samples, especially when the sample contained high concentrations of large-sized sediments. The even distribution of the larger particulates becomes problematic, even with the agitation action of the churn within the splitter. The issue of the potential for uneven distribution of particulates was addressed through the pre-analysis sieving process described in Appendix A

6.1.5 Completeness

The flow data and analytical records for the verification study are 100% complete. There were instances of velocity "dropouts" during some events. A discussion of the calibration procedures for flow data (velocity and stage measurements), including how velocity dropouts were addressed, is provided in Section 6.2.

6.2 Flow Measurement Calibration

6.2.1 Gauge Height Calibration

On October 4, 2005 and May 10, 2006, full pipe static gage height calibrations were completed. Calibration procedures consisted of inflating balls in pipes A and B (see Figure 3-6 of the test plan) to seal off a catchment area upstream of the device. The inlet, unit outlet, and system outlet flow meters were calibrated simultaneously by moving all three meters into the catchment area. Using a garden hose, the water level inside the catchment area were increased by increments of 0.1 to 0.15 ft. Ten to 15 water surface level taped readings were taken for each flow meter. These measurements were then compared to what was recorded by the respective flow meters.

Gage height measurements were also checked periodically under low flow or standing water conditions. Offsets were applied directly to the meters on March 31, 2006 (after event 2 and before event 3) to account for the standing water conditions. Before this date, corrections were made to the stored stage data. Gage height calibration on May 10, 2006 concluded all meters were recording correct water levels and that no stage corrections were necessary.

The pressure transducer probe was used to initiate the bypass sampling routine when a given stage threshold was reached. It is located at on the upstream side of site E. It was calibrated on May 10, 2006. The design of the probe prevented stage from being recorded until water reached a height of 0.58 feet. The stage was offset by 0.84 ft.

6.2.2 Flow Calibrations

Inlet (Site A) Flows

In April of 2006, an automatic dye dilution system was installed to calibrate flow. The injection site for known dye concentrations was located in site A, 10 ft upstream of the weir wall (see Figure 2-6). The location for drawing a sample mixture of stormwater and diluted dye to the fluorometer was at the inlet meter, (a fluorometer measures the concentration of dye fluorescence). A separate gage house for sampling dye and recording data was located adjacent to the sampling gage houses. A dye-dilution event occurred when a given stage threshold was reached at the inlet area/velocity meter.

The equation to convert dye recordings to flow is:

$$Q = q*C/c \qquad (6\text{-}2)$$

where:
Q = flow being measured (L/min)
q = injection rate (mg/L)
C = concentration of injected dye (mg/L)
c = concentration of dye measured (mg/L)

Storms from May 9 and 16, 2006 produced over 650 sample points of calibration at the inlet meter. Comparison of the inlet area/velocity flow and the dye dilution flow yielded ±8% difference per storm, as shown in Figures 6-1 and 6-2. Results from these storms concluded the meter was recording flow accurately.

The device outlet and system outlet meters could not be calibrated by dye dilution because it was unclear how the dye would mix inside of the bypass structure.

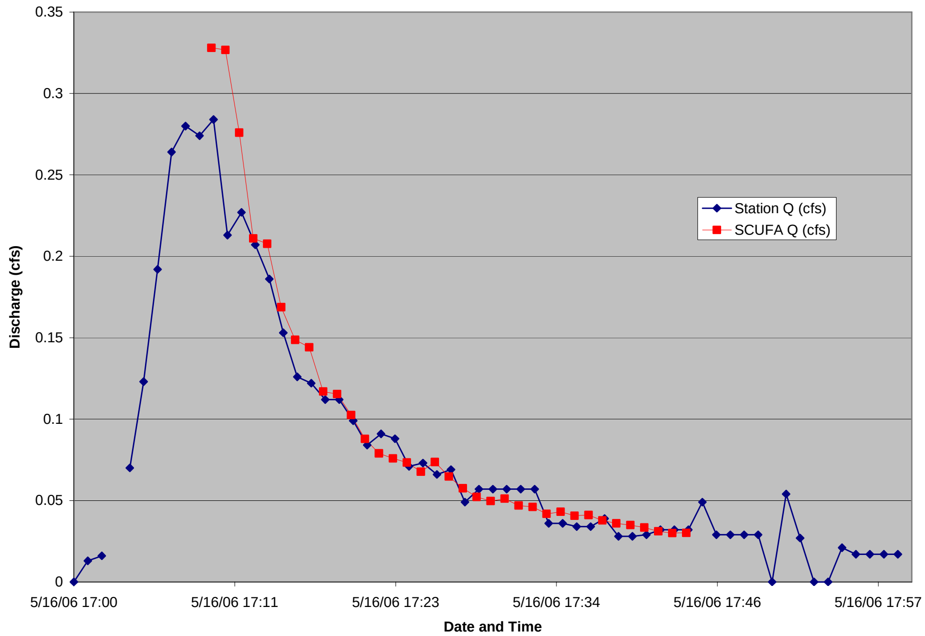


Figure 6-1. Flow calibration plots comparing dye dilution flow to inlet discharge meter for event occurring May 9, 2006.

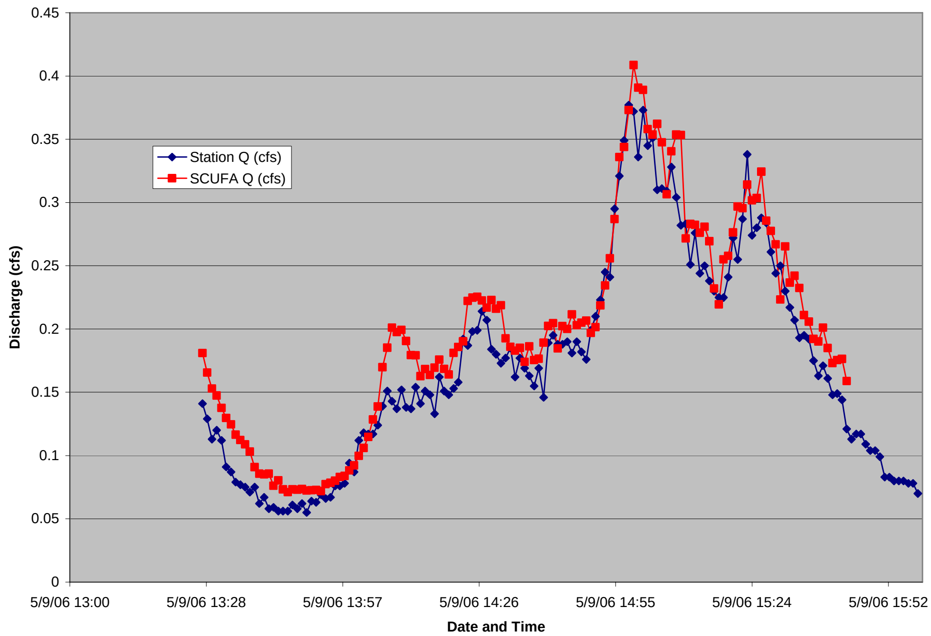


Figure 6-2. Flow calibration plots comparing dye dilution flow to inlet discharge meter for event occurring May 16, 2006.

System (Site D) Outlet Flows

Four of the twenty events sampled recorded bypassing. To predict the amount of water flowing over the weir to the system outlet meter, a relationship correlating flow between the calibrated inlet meter and the system outlet meter was established. The system outlet meter is located at Site D (see Figure 2-6). This relationship is based on four assumptions:

1. No time delay from the inlet and system outlet;
2. The hydrograph rise was the only data used, to eliminate inaccuracy with meters due to possible backwater from the detention pond;
3. Flows in which bypass was recorded were not included in the calibration; and,
4. Events 1 and 2 were not used, because they had a different stage discharge relationship than the dye dilution test because of the shift in stage.

A scatter plot of bypass structure outlet flow to device bypass structure inlet flow indicated that the outlet flows were low (Figure 6-2). The regression line of y = 1.1557x + 0.0326 for a stage above 0.05 was used to correct the system outlet flow inaccuracies. Several other regressions fitted the higher flow regime, but results produced larger errors for overall storm accuracies. For storms without bypassing, the average difference between the inlet and system outlet was -10%.

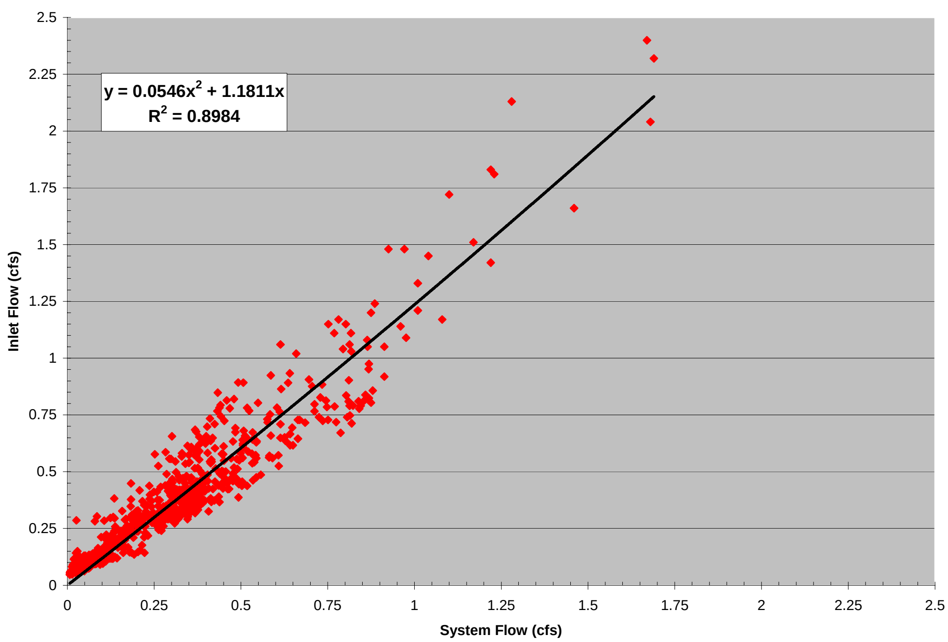


Figure 6-3. System outlet flow rating curve as a function of inlet discharges.

Device (Site C) Outlet Flows

Flows from the device outlet area/velocity meter were not used to calculate loadings for three reasons:

1. Inlet and device outlet flows should be equal and the inlet meter was calibrated;
2. The device outlet flows were over-calculating inlet flow; and,
3. Bypass conditions would affect the device outlet.

6.2.3 Comparison of Runoff Volumes: Rainfall Depth vs. Flow Measurements

A final comparison of instrument measurements was to compare the measured rainfall depth over the drainage area to the runoff volume calculated at the site B or site D flow meter. The rational method was used to convert rainfall depth to runoff volume, using the following equation:

$$Q = CIA \tag{6-3}$$

where:
Q = calculated runoff volume (ft^3)
C = runoff coefficient (unitless)
I = rainfall depth (ft)
A = drainage area (ft^2)

For this study, a runoff area of 1.91 acres (83,200 ft^2) and a runoff coefficient of 1 (i.e. no infiltration or evaporation) was used. The runoff data is summarized in Table 6-6. The calculated runoff was then compared to the flow meter readings as another means to verify accuracy. The flow meter at site B was proven to be the most accurate measurement based on the dye testing, however, this meter does not account for the bypass events where water flowed over the weir. For those four events, the flow at site D was used for the volume calculations. The comparison shows that calculations for 11 of the 20 events are within ±30% of each other, and the median difference was 26%. The highest deviations occurred during events 1 and 2, prior to the stage offset input, as discussed in Section 6.2.1. The calculated runoff volume was higher than the metered runoff volume for all events except events 19 and 20, which would be expected, since the calculated runoff does not account for evaporation, infiltration, or other forms of non-runoff precipitation. There are several possibilities for differences in these readings including:

- Inherent accuracy of each instrument (rain gauge and velocity meter);
- Accuracy of the drainage area delineation (This issue is explained in Chapter 3. It would appear that this phenomena is a factor for runoff events 5, 16, 19 and 20); and,
- Inlet capacity may also affect the volume of rainfall entering the storm sewer system.

Table 6-5. Comparison of Calculated vs. Metered Runoff Volumes

Event No.	Rainfall Depth (in.)	Calculated Runoff Volume (ft^3)	Metered Runoff Volume (ft^3)	Difference (%)
1	0.71	4,930	1,884	-62
2	0.43	2,995	1,374	-54
3	1.01	6,989	5,910	-15
4	0.37	2,558	1,979	-23
5	1.13	7,862	7,448	-5
6	1.65	11,440	8,484	-26
7	0.25	1,733	1,572	-9
8	0.37	2,558	2,091	-18
9	0.86	5,990	5,037	-16
10	0.23	1,560	1,313	-16
11	0.79	5,491	4,251	-23
12	0.36	2,510	1,426	-43
13	1.87	12,972	10,990	-15
14	0.96	6,656	4,683	-30
15	0.36	2,496	1,866	-25
16	2.16	14,976	14,869	-1
17	0.71	4,923	3,663	-26
18	0.29	2,011	1,305	-35
19	1.60	11,093	14,671	32
20	1.35	9,360	20,896	123

After reviewing the data and the site conditions, it appears that the adjacent recycling center property provided runoff to the monitoring area during storm events with large rainfall depths, resulting in flows greater than the Downstream Defender® design capacity. Figure 3-4 shows evidence that runoff from the recycling center property (north of the Water Utility property) may cross over the speed bump diversion located on the boundary between the two properties. An estimation of the contribution of runoff from the adjacent property, based on the runoff data and visual observations at the site, indicate that the contribution from the adjacent property during large storms could have increased the drainage area size to 5.7 acres (an addition of 3.8 acres above the original 1.91 acres). This estimate will vary by rain depth, intensity, and the capacity of the ground inlet at the driveway between the properties.

6.3 Other Monitoring Complications

After the unit was installed, but before the first event was sampled, an observation that stormwater was taking several hours to drain out of the device was noted. This caused standing water at the system outlet pipe and may affect the performance of the device. The bypass structure outlet pipe drains into a detention pond where the elevations of the pond are controlled by a standpipe. The pond's standpipe controlled the elevation of the pond to be less than 1 ft below the bypass outlet pipe elevation. During some events, this likely caused standing water at the bypass structure outlet pipe. In January 2006, a larger opening in the standpipe was created to lower pond elevation and reduce the potential backwater effect of the pond. The drainage issue was not observed during the test period.

A few storms during the summer of 2006 were missed due to power failures with the samplers. High summer temperatures increased the power needs of the refrigerators. When the sampler tried to take a sample, there was not enough power to run the pumps, resulting in power failures. Adding an extra battery was added to the system alleviated this problem.

Sample tubing was replaced at the inlet sampler in June 2006 due to damage from rodents to the line. This caused an event on June 10, 2006 to be missed.

The temperature probe did not record correctly after May 1, 2006. Temperature reading from another site stormwater monitoring site, two miles northeast of the Downstream Defender®, was substituted for the remaining storms. The substitute probe was installed in May, 2006 at a downtown Madison, Wisconsin parking lot stormwater monitoring site.

Chapter 7
Operations and Maintenance Activities

7.1 System Operation and Maintenance

Hydro International recommends inspecting the system every six months in the first year of operation to check for accumulated sediment depth in the sump. Hydro International also recommends that the 6-foot diameter unit be cleaned out if the accumulated sediment reaches 24 inches in depth.

The TO followed the manufacturer's guidelines for maintenance on the Downstream Defender® during the verification testing. Installation of the Downstream Defender® was completed in the fall of 2004. In the fall of 2005 the monitoring equipment was installed and initial monitoring began in spring, 2006. Table 7-1 summarizes O&M activities undertaken by the TO and USGS once verification testing was initiated.

Table 7-1. Operation and Maintenance During Verification Testing

Date	Activity	Personnel Time/Cost
10/04/05	Site visit with P. Davison (NSF Int.); L. Glennon (Hydro Intr.); J. Horwatich (USGS); Jill Kendall (City of Madison) J. Bachhuber & J. Hurlebaus (Earth Tech. Decided to hold off pre-monitoring period cleaning until after the final monitoring instrument checks Field elevation measurements obtained: ▪ 5.15 ft from manhole (MH) rim to the bottom of bypass box downstream of weir; ▪ 5.16 ft from MH rim to the bottom of the bypass box upstream of weir; ▪ Sediment depth was about 2 in.; ▪ Water surface was 0.91 ft below the invert of the pond inlet pipe; ▪ Pond outlet structure has three circular openings. The lowest one is 0.8 ft diameter and the bottom was at the water surface elevation on 10/4/05. The middle opening was 1.4 ft from the water surface elevation and has a 1 ft diameter. The highest opening is also 1 ft diameter and the bottom of this opening was 1.65 ft from the water surface elevation.	6 staff; approximately 3 hours at the site. Not directly related to maintenance costs
11/09/05	City of Madison Vac-All equipment removed all possible sediment. Also cleaned flow-splitter box, outer annulus (floatables area) and main sump area.	2 city staff @ 3 hours each = 6 staff hours

Date	Activity	Personnel Time/Cost
11/10/05	J. Bachhuber & J. Hurlebaus verified cleanout. Following measurements were made: • MH rim to water surface in Downstream Defender® center shaft: 7.8 ft; • Water depth in Downstream Defender® 3.0 ft; • No sediment was detected with probe; • Floatables chamber was clear; • Small amount of sediment in flow-splitter box corners; • Less than ¼ in. of sediment in flow-splitter box.	2 Earth Tech staff @ 1 hour each = 2 staff hours.
1/13/06	USGS personnel enlarged the low-flow opening to the detention pond to reduce the frequency and potential for backwater effects on the flow-splitter box outlet pipe.	2 USGS personnel @ 4 hours each = 8 hours Not directly related to maintenance costs
3/1/06 – 9/15/06	Routine USGS visits to site to maintain monitoring equipment. Downstream Defender® checked for backwater and/or debris clogging operation. No problems found.	
09/15/07	Final post-monitoring Downstream Defender® cleanout. Summary of activity and results provided in Section 7.2.	2 USGS, 2 Earth Tech, & 2 City staff @ 8 hrs each = 48 staff hours. This time does not include the sediment drying, measuring and weighing effort.

7.2 Description of Post Monitoring Cleanout and Results

7.2.1 Background

On September 15, 2006, the Downstream Defender® was cleaned out so that as much of the solid material as possible from the device could be dried, weighed, and characterized. The weather was sunny and clear, with temperatures in the mid 70s, and there had been no rain for the previous two weeks.

The general steps followed were:

1. Measure sediment depth and water depth before starting;
2. Decant standing water from Downstream Defender® to pond with pump;
3. Measure drawdown depth and take TSS samples during process to calculate sediment mass of decanted water;
4. Use city Vac-All to remove remaining material; and,
5. Transport material in truck to USGS and deposit in large constructed tank for drying, weighing, and analysis.

7.2.2 Field Measurements

Field measurements and observations are outlined in Table 7-2, and resulted in an estimated retained materials depth of 0.35 ft.

Table 7-2. Field Measurements During Post-Monitoring Cleanout Activities

No.	Measurement Description	Result (ft)
1.	Top of water in Downstream Defender® to rim of center shaft	2.00
2.	Rim to top of retained solids (3 replicates)	4.71
		5.10
		5.10
3.	Average depth of last two replaces of measurement 2	5.10
4.	Rim to bottom of chamber	5.45
5.	Calculated retained solids depth (measurement 4 – measurement 3)	0.35

7.2.3 Measurement Results

Five sub-samples of the retained solids were transported to the USGS Sediment Laboratory in Iowa City, Iowa for particle size distribution analysis. Table 7-3 summarizes the results of the material analysis. The term "sediment" is avoided in this analysis, because much of the material consisted of leaves, trash, and larger debris. The weight did not take into account the larger debris, which was removed prior to drying and weighing. As shown in Table 7-3, approximately 93% of the sediment retained in the sediment chamber had a particle size of 125 µm or larger. Figure 7-1 shows that the greatest proportion of sediments were in the 250 to 500 µm range.

The actual total mass of the material removed from the Downstream Defender® had a dry weight of 416 pounds.

Table 7-3. Retained Solids Particle Size Distribution Analysis

Sieve Size (µm)	Sieve Passage Rate (%)					Mean (%)
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	
<16,000	97.2	100	100	100	100	99.4
<8,000	94.8	97.5	96.3	97.6	98.2	96.9
<4,000	89.7	93.3	91.9	94.6	95.0	92.9
<2,000	80.0	82.7	84.2	87.4	87.9	84.4
<1,000	64.8	68.1	70.2	75.6	74.9	70.7
<500	41.0	42.2	44.7	50.5	49.8	45.6
<250	17.4	18.0	17.1	21.9	20.9	19.1
<125	7.1	7.3	5.8	8.3	7.4	7.2
<63	3.5	3.9	2.7	4.0	3.3	3.5
<31	2.2	2.7	2.4	2.5	2.0	2.4
<16	1.0	1.4	0.9	1.3	0.9	1.1
<8	0.5	0.6	0.6	0.7	0.5	0.6
<4	0.3	0.5	0.5	0.6	0.4	0.5

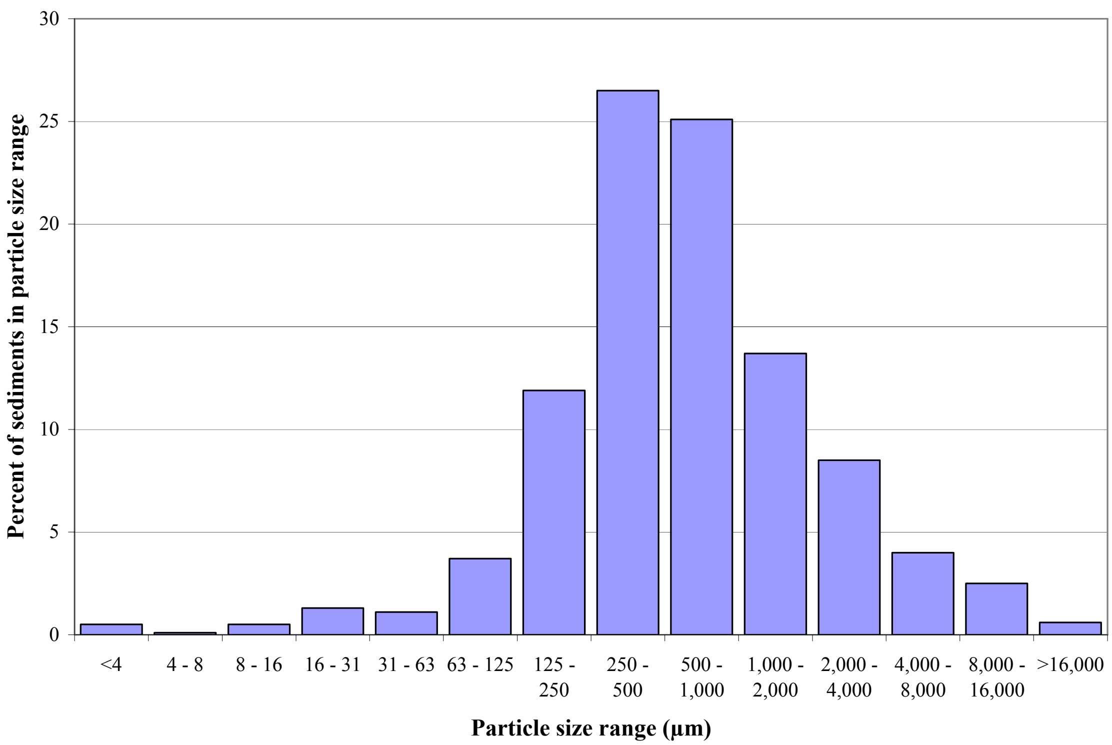


Figure 7-1. Graphical representation of retained solids particle size distribution range.

Chapter 8
Vendor Comments

The following evaluation was performed by the vendor, Hydro International, and does not represent verified data.

Hydro International uses proprietary software to predict the performance of the Downstream Defender® and its other stormwater source area management products. The software predicts the sediment removal percentage as a function of particle gradation, flow rates, and water temperature. This software was used to create the anticipated performance curves for Maine DOT road sand and F-110 silica sand presented in Figure 2.8 as part of the vendor's performance claims.

Based on the particle size distribution data generated as part of this study, the software was used to estimate percent sediment removal at flow rates ranging from 0.5 to 3 cfs. This curve is expressed graphically in Figure 8.1.

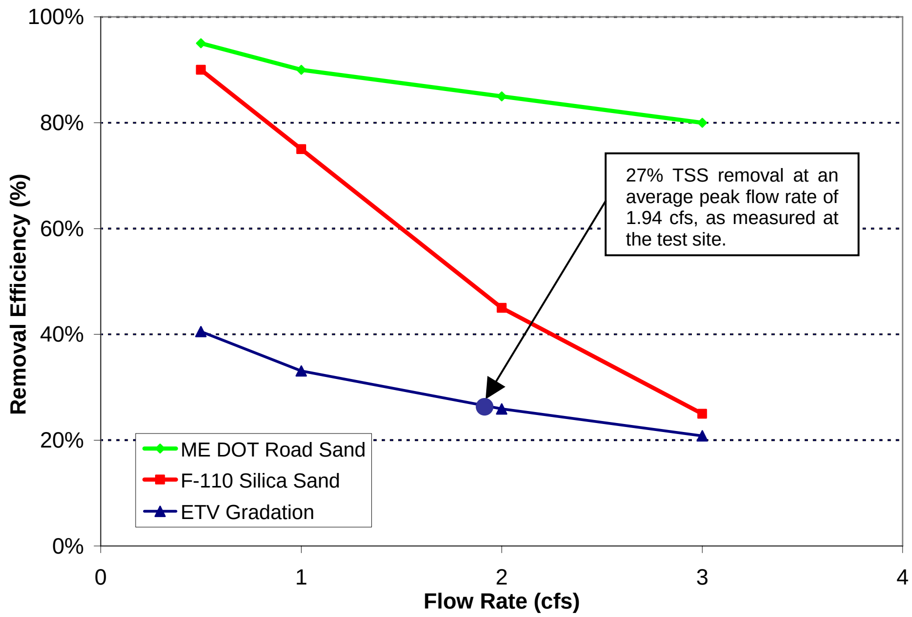


Figure 8-1. Estimated removal efficiencies for ME DOT road sand, F-110 silica sand, and test site sediment at 15 °C.

Based on the data recorded during the 20 qualified events, the average peak flow rate was 1.94 cfs and the TSS removal efficiency (as measured by sum of loads) was 27%, which is in line with the ETV gradation curve predicted by Hydro International's software package. Therefore, for the particle size gradation encountered at this test site, the Downstream Defender® performed in line with expectations and in this regard met its performance claim.

Chapter 9
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Glossary

Accuracy - a measure of the closeness of an individual measurement or the average of a number of measurements to the true value and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Comparability – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

Completeness – a quantitative term that expresses confidence that all necessary data have been included.

Precision - a measure of the agreement between replicate measurements of the same property made under similar conditions.

Protocol – a written document that clearly states the objectives, goals, scope and procedures for the study. A protocol shall be used for reference during Vendor participation in the verification testing program.

Quality Assurance Project Plan – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

Residuals – the waste streams, excluding final outlet, which are retained by or discharged from the technology.

Representativeness - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point, a process condition, or environmental condition.

Wet-Weather Flows Stakeholder Advisory Group - a group of individuals consisting of any or all of the following: buyers and users of in drain removal and other technologies, developers and Vendors, consulting engineers, the finance and export communities, and permit writers and regulators.

Standard Operating Procedure – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Technology Panel - a group of individuals with expertise and knowledge of stormwater treatment technologies.

Testing Organization – an independent organization qualified by the Verification Organization to conduct studies and testing of mercury amalgam removal technologies in accordance with protocols and Test Plans.

Vendor – a business that assembles or sells treatment equipment.

Verification – to establish evidence on the performance of in drain treatment technologies under specific conditions, following a predetermined study protocol(s) and Test Plan(s).

Verification Organization – an organization qualified by EPA to verify environmental technologies and to issue Verification Statements and Verification Reports.

Verification Report – a written document containing all raw and analyzed data, all QA/QC data sheets, descriptions of all collected data, a detailed description of all procedures and methods used in the verification testing, and all QA/QC results. The Test Plan(s) shall be included as part of this document.

Verification Statement – a document that summarizes the Verification Report reviewed and approved and signed by EPA and NSF.

Verification Test Plan – A written document prepared to describe the procedures for conducting a test or study according to the verification protocol requirements for the application of in drain treatment technology. At a minimum, the Test Plan shall include detailed instructions for sample and data collection, sample handling and preservation, precision, accuracy, goals, and quality assurance and quality control requirements relevant to the technology and application.

Appendices